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New Energy Service as a Part of Technical Due Diligence in Apartment Buildings

Master's thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Technology.

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Abstract of master's thesis

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Abstract

Technical due diligence is a service used to estimate the risks in the real estate transaction. It takes into account technical risks related to physical condition together with planning, building permits and regulations. The condition assessment made in the technical due diligence proposes a long term renovation plan for the building. Typically the Technical due diligence and the long term renovation plan does not take sides to energy consumption of the building or the fact how the implemented long term renovation plan effects on the buildings energy consumption. This master's thesis makes a new energy service as a part of technical due diligence, which takes into account the effects of the implemented tasks of the long term renovation plan into buildings energy consumption. In this master's thesis the new energy service as a part of technical due diligence covers only the apartment buildings.

The developed concept of the new energy service is introduced phase by phase as part of technical due diligence process in real estate transactions. In the end of the thesis the new service and the suitability of the calculation tool is tested in two different case studies.

The new energy service developed in this master's thesis is a value adding side service as a part of technical due diligence in apartment buildings. It gives the customer a good view of the energy efficiency potential of the building and a good knowledge of the effects of the long term renovation tasks to the energy consumption and fixed costs of the building. All the energy consumption comparisons are made to the regulations under the round of comments (14.3.2016) towards the nearly zero energy buildings and adopted to the reconstruction work.

In addition the new service also gives the customer the payback periods and effects to the energy consumption in cases the technical system is upgraded to even better level than the new requirement for the nearly zero energy buildings requires.

Keywords Technical Due Diligence, LTP, Energy Efficiency Potential.

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Tiivistelmä

Tekninen due diligence -selvitys on kiinteistötransaktioprosessin aikana tehtävä riskien hallintatoimenpide. Siinä otetaan huomioon niin rakennuksen fyysinen kunto kuin kaavoihin, rakennuslupiin ja määräyksiin liittyvät lainsäädännölliset tekniset riskit. Teknisen due diligencen aikana tehtävässä kuntokatselmuksessa ehdotetaan kiinteistölle pitkän tähtäimen kunnossapitosuunnitelmaa. Normaalisti tekninen due diligence ei ota kantaa pitkän tähtäimen suunnitelmassa esitettyjen korjaustoimenpiteiden toteutuksen vaikutuksista kiinteistön energiankulutukseen. Tämä diplomityö toteuttaa uuden energiapalvelun teknisen due diligencen lisäpalveluksi. Palvelu huomioi pitkän tähtäimen kunnossapitosuunnitelman toteutuneet toimenpiteet ja niiden vaikutuksen kiinteistön energiankulutukseen. Tässä diplomityössä kehitetty energiapalvelu kattaa vain asuinkerrostalot.

Työssä kehitetty uusi energiapalvelu esitellään käymällä sen toteutustapa läpi vaiheelta osana kiinteistöjen teknistä due diligencea prosessia. Työn lopussa luotua palvelua ja laskentatyökalun soveltuvuutta testataan kahdessa kohdekiinteistössä.

Uusi energiapalvelu, joka on kehitetty tässä diplomityössä, on lisäarvoa antava lisäpalvelu teknisen due diligencen yhteydessä. Palvelu kertoo asiakkaalle kiinteistön energiatehokkuuspotentiaalin ja antaa hyvän kuvan pitkän tähtäimen kunnossapitosuunnitelman vaikutuksista kiinteistön energiankulutukseen ja siten kiinteisiin kuluihin. Diplomityön kaikki energiankäytön vertailut on tehty kommenttikierroksella 14.3.2016 menneen uuden Suomen rakennusmääräyskokoelman arvoilla, jotka tähtäävät lähes nollaenergiarakentamiseen. Ohjeen arvoja on työssä sovellettu siten, että ne koskisivat myös korjausrakentamista.

Lisäarvona uusi energiapalvelu kertoo asiakkaalle kiinteistön mahdollisen energiankulutuksen ja investoinnin takaisinmaksuajan, jos pitkän tähtäimen suunnitelmassa esitetty korjauskehitys toteutetaan tekniikaltaan lähes nollaenergiarakennukselta vaadittua minimiarvoa paremmalla tekniikalla.

Avainsanat Tekninen Due Diligence, PTS, Energitehokkuuspotentiaali.

Foreword

This master thesis has been carried out as a development project to Ramboll Finland Oy. As a supervisor of the thesis was Risto Kosonen, a professor of HVAC Technology at Aalto University School of Engineering and as an instructor was Markku Ahonen, a Master of Science and an expert in the field of HVAC engineering and energy efficiency in Ramboll Finland Oy. I would like to thank both of you for your work towards this thesis and give special thanks to Professor Kosonen for reminding me that Alice wouldn't ever find her way out from the Wonderland without asking the Cheshire cat for advice first. And as we all remember, the Cheshire cat can be one pain in the ass…

There would not be enough printer ink to express the feelings I have been through during this journey in Otaniemi; similarly, these pages would not suffice to acknowledge all of you who have stood by me or had influence on me over the past years. You, who are reading this text, you know exactly how much you matter to me.

But no matter what I wrote before this paragraph, I need to highlight couple things and people from this journey from high school graduate to Master of Science in Technology. First I want to thank PUS-hockey for lifelong experiences on and off the ice. Koneinsinöörikilta, Polyteekkarimuseo and Ayy for every minute I have had a chance to do big and yes from my mouth, epic events and things with awesome people.

But as we all know, this foreword would not be anything without telling you all that after all, this Master's thesis was *vartin homma*! Teekkarijaosto 12 and 13, thank you!

ITMK12 or better known as JarITMK, you are all special to me! I don't find the words to tell you much I appreciate all of you, so I just say, thank you for all the special time we have had during the past years. P.S. Thanks for the morning wake up!

Matti Nurmi, thanks for the last seven years of friendship! It has been an honour to spend time with you with different projects between the bottom of the Nordic sea and skiing hill, not forgetting the good old times spent with different courses. ENEposse, Matias Korkka, Mika Tarhala, Olli Muhonen and Tero Juutilainen, thanks for the long lasting friendship and reminding me that there is also life outside Otaniemi and there is no hurry to come to the working life. Teemu Putkinen, thank you for the good and competitive times in our master's thesis group therapy sessions and weekends during the most desperate moments of this work. Jere, Katharina and Otso, thank you for proofreading and commenting the thesis. Although, it is only because of the heat flow.

Isä, Äiti ja siskoni Petra, kiitos kaikesta tuesta, kannustuksesta ja ennen kaikkea ymmärryksestä tällä matkalla, joka osoittautui pidemmäksi, kivisemmäksi ja raskaammaksi, mutta sitäkin opettavaisemmaksi ja hauskemmaksi kuin koskaan osasin siltä odottaa. Omia fiiliksiä tämän tekstin äärellä on vaikea pukea sanoiksi. Kiitos siis vielä kerran!

Things do not change, we change.

Espoo, July 25th, 2016

Jari Isaksson

Contents

Symbols

A	[€]	Yearly return on the energy savings investment
A	[m²]	Gross area of the building
A_{bf}	[m²]	Area of the base floor
A_{m}	[m²]	Area connected to inside air
A_{roof}	[m²]	Area of the roof
$A_{\mathrm{win,tot}}$	[m²]	Total window area
α_{j}		Absorption factor of external surface of the wall
α_{mi}	[W/m²K]	heat transfer factor between inside air and the nodal point
a_{n}''		Discounting factor taking the escalation into consideration
$C_{\mathrm{m,n}}$	[J/K]	Heat capacity of the structure nodal point n
C_{s}	[J/K]	Heat capacity of the air nodal point
c_{pi}	[kJ/kgK]	Specific heat capacity of air
c_{pw}	[kJ/kgK]	Specific heat capacity of water
dt		Time differential
$E_{\mathrm{DHW,net}}$	[kWh]	Energy of domestic hot water
F_f		Frame factor of the window
f_{e}		Escalation
G_{AC}	[W/K]	Conductance of the air conditioning
G_{hb}	[W/K]	Conductance of the thermal bridges
G_{inf}	[W/K]	Conductance of the infiltration air
G_{mi}	[W/K]	Conductance between inside air and structure
$G_{\mathrm{mi,n}}$	[W/K]	Conductance of the enclosing structure and outside air
$G_{\mathrm{m,tot}}$	[W/K]	Total conductance
G_{sm}	[W/K]	Conductance's in series
$G_{\mathrm{sm,n}}$	[W/K]	Conductance of the enclosing structure and inside air
G_{win}	[W/K]	Conductance of the windows
g		G-value of the window
H_{floor}	[m]	Height of the floor
h_{j}	[W/m²K]	Convective heat transfer coefficient for the external surface of the wall
I_0	[€]	Investment cost
i		Real interest rate
k	[W/Km]	Average thermal conductivity
$l_{\mathrm{ew/bf}}$	[m]	Length of the joint between the external wall and roof
$l_{\mathrm{ew/ew}}$	[m]	Length of the joint between the corners of two external wall
$l_{\mathrm{ew/if}}$	[m]	Length of the joint between external wall and intermediate floor
$l_{\mathrm{ew/roof}}$	[m]	Length of the joint between the external wall and roof
$l_{\mathrm{ew/win}}$	[m]	Length of the joint between the external walls and windows
$l_{\mathrm{win,norm}}$	[m]	Length of the typical window
N	[a]	Payback period
n	[a]	Investment time
n_{AC}		Adjustment factor of the air flows
n_{floor}		Quantity of floors
P	[€]	Net present value of the investment
$P_{\mathrm{heating\ coil}}$	[W]	Power produced by the heating coil

P_{HR}	[W]	Heat power obtained with heat recovery
$P_{\mathrm{L,AC,Net}}$	[W]	Power needed to heat up the supply air
q_{AC}	[m³/s]	Air flow rate of the air conditioning system
q_{in}	[m³/s]	Supply air flow of the building
q_{inf}	[m³/s]	Flow of the infiltration air
q_{m}	[m³/m²]	Planned supply air flow of the building
R		Proportion of the supply to exhaust air
$R_{1\mathrm{s}}$	[K/W]	Thermal resistance of the wall
r_{e}		Real interest rate taking escalation into consideration
SFP	[kW/(m³/s)]	Specific fan power
T_{HR}	[K]	Temperature of the supply air after the heat recovery
$T_{\mathrm{HR,floating}}$	[K]	Temperature of the air before heating or cooling coil
T_{ice}	[K]	Minimum temperature of the extract air
T_{if}	[K]	Temperature of the intermediate floor
$T_{\mathrm{if-1}}$	[K]	Previous temperature of the intermediate floor
$T_{\mathrm{m,n}}$	[K]	Temperature of the structure nodal point n
$T_{\mathrm{m,n-1}}$	[K]	Temperature of the previous time step of the nodal point n
T_{p}	[K]	Temperature of the exhaust air
T_{s}	[K]	Temperature of the inside air
$T_{\mathrm{s-1}}$	[K]	Previous temperature of the inside air
$T_{\mathrm{s,set}}$	[K]	Set point temperature of inside air
T_{sun}	[K]	Sun temperature
T_{sup}	[K]	Temperature of the outside air on the surface of the enclosing structures
T_{u}	[K]	Temperature of the outside air
$U_{\mathrm{m,tot}}$	[W/m²K]	U-value of the structure
V_{exh}	[m³]	Yearly exhaust air flow
V_{sup}	[m³]	Yearly supply air flow of the building
V_{w}	[m³]	Volume of the consumed water
ΔT	[K]	Temperature difference
ΔT_{i}	[K]	Temperature difference between the outside temperature and the set point temperature
Δt	[h]	Time step
θ	[°]	The angle of the direct radiation to the window
η_{HR}		Efficiency of the heat recovery
η_{t}		Temperature efficiency of the heat recovery
η_{temp}		Temperature efficiency when the air flows are in balance
$\lambda_{\mathrm{DHW,uti}}$		Portion of positive heat flow from domestic hot water to spaces
$\emptyset_{\mathrm{m}}$		Factor for thermal loads affecting to the structural nodal points
Φ_{i}	[W]	Convective heat power to inside air nodal point
Φ_{hc}	[W]	Heating or cooling power
Φ_{m}	[W]	Emittance effecting to the structure nodal point
Φ_{sun}	[W]	Direct radiation power of the sun through the window
ρ_{i}	[kg/m³]	Density of air
ρ_{w}	[kg/m³]	Density of water

τ		The penetration factor of the sunshade
$\tau_{condensate}$		Factor to generate the extra power needed in phase change
$\phi_{AC,exh}$	[kW]	Yearly electricity consumption of the exhaust fan
$\phi_{AC,sup}$	[kW]	Yearly electricity consumption of the supply fan
ϕ_{DHW}	[kW]	Heating power of the domestic hot water
$\phi_{DHW,loss}$	[W/m²]	Heat losses of the domestic hot water ring duct
ϕ_{sun}	[W/m²]	Intensity of the radiation to the external surface of the window
$\phi_{sun,tot}$	[W/m²]	Specific radiant power for the wall

Abbreviations

ACEE	American Council for an Energy-efficient Economy
BAT	Best Available Technic
BREEAM	Building Research Establishment Environmental Assessment Methodology
CO_2	Carbon Dioxide
COP	Coefficient of Performance
CSE	Cost of Saved Energy
DD	Due Diligence
EDD	Environmental Due Diligence
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EU	European Union
FDD	Financial Due Diligence
GDD	Green Due Diligence
HVAC	Heating, Ventilation and Air Conditioning
HVACEA	Heating, Ventilation, Air Conditioning, Electricity, Automation
IEA	International Energy Agency
KH-card	Finnish Property Management Card
LED	Light-emitting diode
LCC	Life-Cycle Cost
LDD	Legal Due Diligence
LEED	Leadership in Energy and Environmental Design
LTP	Long Term Renovation Planning
nZEB	Nearly Zero Energy Building
nZEBR	Nearly Zero Energy Building Renovation
PBP	Payback Period
REDD	Real Estate Due Diligence
RIL	Suomen Rakennusinsinöörien Liitto
SFP	Specific Fan Power [$kW/(m^3/s)$]
TDD	Technical Due Diligence
TRC	Total Resource Cost
U-Value	Overall Heat Transfer Coefficient

1 Introduction

The subscriber of this thesis is a department in Ramboll Finland Oy, which offers a comprehensive due diligence service that measures the technical value of real estate. To stay ahead and offer a better service to its customers, the basic goal of the department is to develop new and innovative ways to give added value to the customer in a way that is cost efficient and relevant, giving both customers and tender an opportunity for a profitable business. The purpose of this thesis is to create a new value-adding energy service to technical due diligence that can be marketed as a value and knowledge adding side service in the real estate due diligence. The new service gives the potential buyer a better vision of the fixed cost in case of energy consumption and a better knowledge of the influence in fixed cost when buildings services or technical equipment are changed to more energy efficient according to their maintenance periods and technical lifetime. Also the possibility of a system upgrade is taken into account in this service, and the payback period for the technical improvement is calculated. In this kind of business, it is important to understand that the customers are not always aware of their needs or that the customers do not know what the best available technic is. In cases like this, it is good to understand the customer's needs and offer a service package that is capable of satisfying the need perfectly. (Arantola et al., 2009, p. 3-4)

1.1 Background

Buildings are recognised as the largest energy consuming sector in the world economy and they have a central position in the European Union's energy efficiency politics because the building sector uses over 40 percent of the final energy consumption if the construction is also included in the calculation (IEA, 2008 and 2014). Thus, buildings can be seen as being the greatest culprit behind or having the greatest potential in solving our climate crisis, depending on how pessimistic or optimistic one chooses to be. From Figures 1 and 2, we can clearly see that also in Finland the end usage of energy and electricity in the building sector is high.

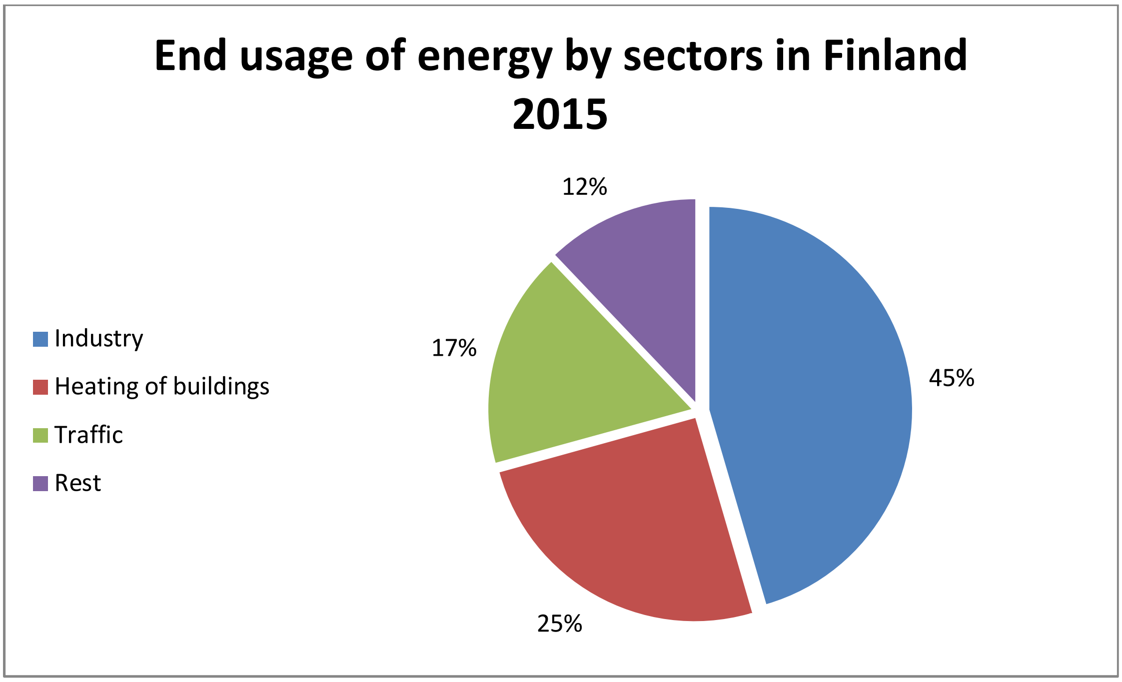

Figure 1. End usage of energy in Finland 2015 (Tilastokeskus, 2015)

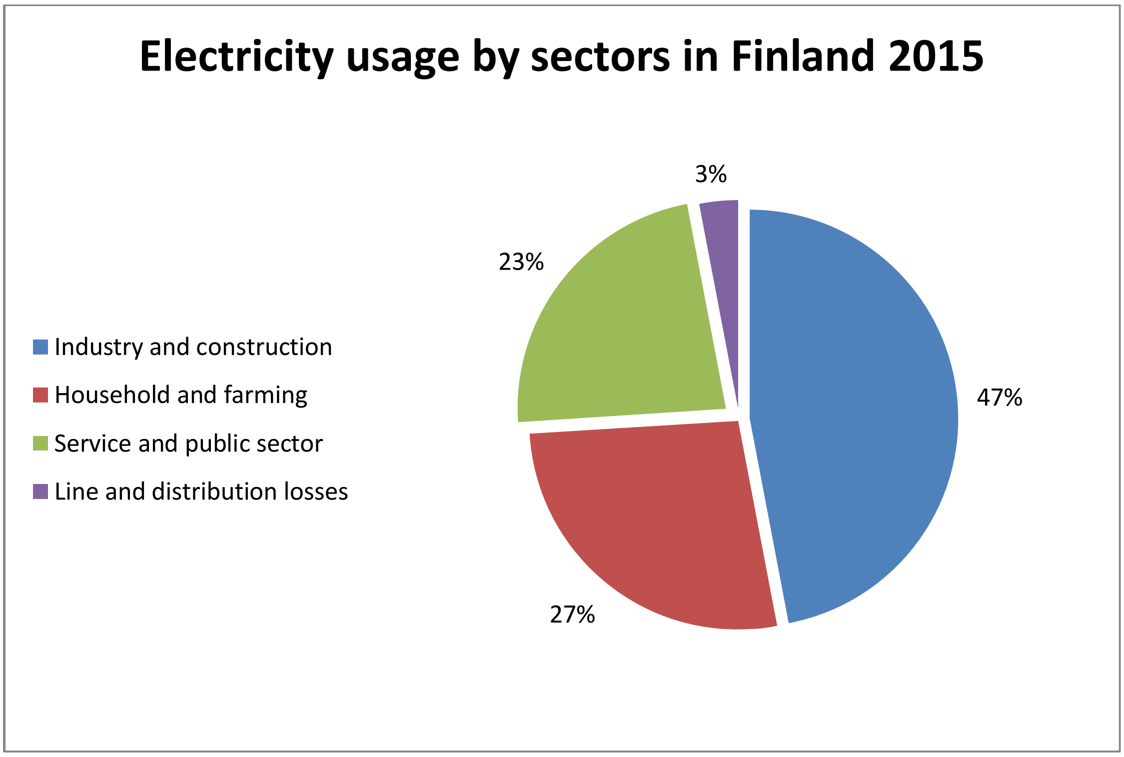

Figure 2. Electricity usages of different sectors in Finland 2015 (Tilastokeskus, 2015)

As a conclusion from Figures 1 and 2, it can be said that buildings use a lot of energy, which comes to sophistry that buildings hold great potential in terms of energy efficiency. The time to reach the whole potential is rather long, because of the inertia in the renewal of the building stock. The lifespan of a building can be rather long from 50 to 100 years and typically the building is renovated only once or twice during its lifespan. The overall renewal rate of the building stock is averagely around 1 percent annually for European countries (Meeus et al., 2012). Major energy efficiency improvements are averagely made during these bigger renovations but the typical technical lifetime of building services engineering is shorter. This means that some of the energy efficiency potential can be harnessed when the technical lifecycle of the technical building services comes to an end. (Häkkinen et al., 2012, p. 4)

Buildings and real estates have been an emerging market in the Nordic region since the economic crises of 2008. In Figure 3, it is clearly seen that between years 2008 and 2014 the annual transaction volumes of real estates in the Nordic have been increasing almost every single year. According to Newsec (2015 and 2016), the transaction volumes in Nordic region have risen also 2015 and the forecast for year 2016 is also positive excluding Finland that is forecasted to fall from 14 billion euros to approximately 9 billion euros. (Newsec, 2015 and 2016)

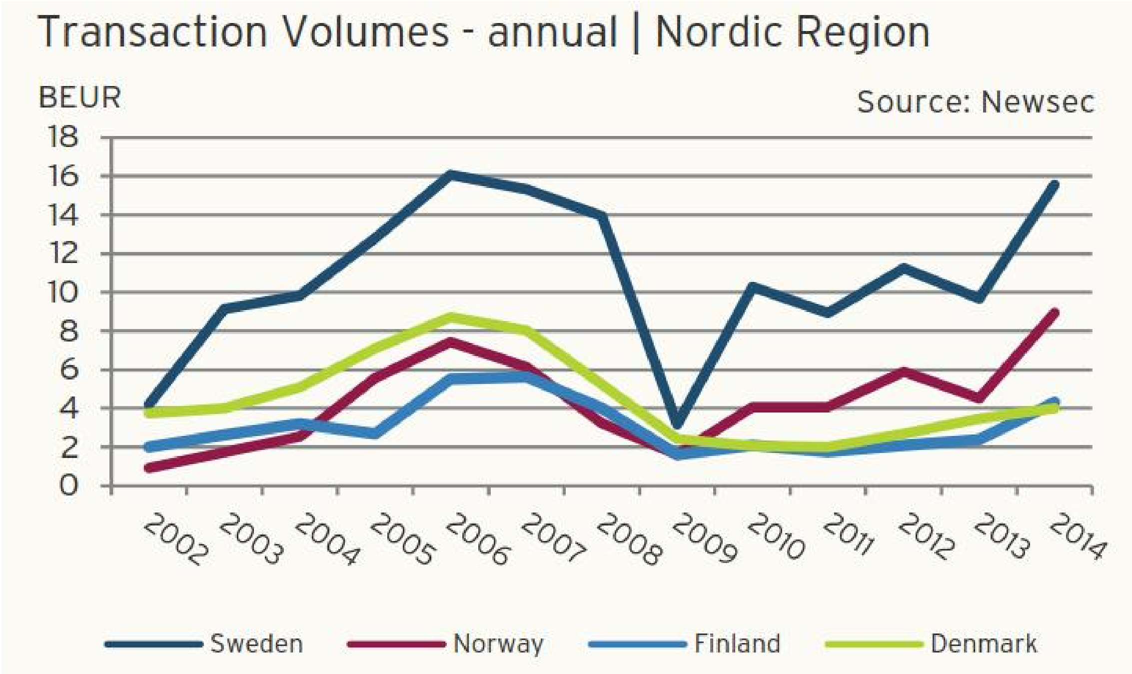

Figure 3. Annual transaction volumes in the Nordic region between years 2002-2014. (Newsec, 2015, p. 8)

Since the volume of transactions has been increasing also the Due Diligence (or in short DD) evaluation has heavy demand while buyers and vendors evaluate the risk of real estate transactions. In real estate due diligence, the typical approach to risk management before transactions is made from financial, technical, environmental and legal perspective. These studies in Finland do not typically take energy or energy efficiency into account excluding the annual energy performance of a building, that is, the so-called E-value and energy certificate, which is obligatory when selling or renting a building. E-value is only mentioned in the DD studies and thus, an energy certificate is obligatory in the transaction process. The valid energy certificate is inspected but not observed. (Finlex, 2013)

Long Term Renovation Planning (LTP) is also incorporated to DD studies. LTP comprises building maintenance needs, costs and schedule typically for the next 10 to 15 years. It is basically based on condition assessments completed with condition studies. LTP studies focus on electrical and mechanical systems as well as structural elements. In LTP made especially for the technical due diligence, every proposal for action is treated as individual without any perspective to energy efficiency or improvements to system or technology. On the other hand, energy efficiency should be an important factor on how the buyer estimates the fixed costs of the real estate energy in the future.

Many of the action plans made in the LTP have an impact on energy economy if they are executed. This is an exact development point in LTP and DD studies and also valuable information to the potential buyer or vendor of the building or real estate. That is why this thesis tries to build a new overarching energy service as a part of technical due diligence.

1.2 Research Objective and Outline

The objective of this thesis is to develop a new energy service as a part of technical due diligence in apartment houses. The develop service should use only the action plans determined in the long-term renovation plan made during the field study as a part of technical due diligence condition survey. The point of the new energy service is to determine the amount of energy saved and effect to the fixed costs of the apartment house, when the old technical system or equipment has come to the end of its technical lifetime and is changed for technical reasons to a new system of the same kind, which meets the energy efficiency demands of today. As a second point of view in this new service, it determinates the possible energy savings and payback period for situations when the system or equipment is upgraded to a better one or on the other hand calculate the possible rebound effect to the fixed cost if the system is for example upgraded to achieve a better indoor air quality or heat circumstances.

As an outcome of the thesis, there will be a service for the customer that reports the energy savings obtained from the possible installations of new systems and compares them to the old situation. This way, it is easier for the customer to make decisions to update or upgrade the technically outdated systems, when they can immediately see the effect on the fixed costs during the investment period.

The created new service is tested in two case buildings that are selected from the ongoing projects in Ramboll Finland Oy. The study is carried out as an independent work beside the normal DD-study made by the technical experts of Ramboll Finland Oy.

The calculation method used to study the energy usage of an apartment building in this thesis is based on a simplified heat dynamic model of an apartment building, using energy balance and nodal point calculations of the building. This calculation method was chosen to be implemented in the thesis over existing calculation software's, because there was a need for quick and efficient calculating method, which does not need time-consuming specific and detailed models of the building to achieve an accurate outcome and which could be modified easily to further studies of, for example office buildings. In the thesis, the chosen equipment changes or building element renovations are based on the findings made in the condition assessment and LTP during the technical due diligence. The objective of LTP is to recognize the building services that are coming to the end of their technical lifespan in next 10 to 15 years and to achieve the starting values and the calculated systems for the energy saving calculations.

1.3 Limitations

The thesis is limited to concern only apartment houses because both of the case studies where the new energy service is tested. Due to the character of the due diligence, it is normal that the study and reporting are made in a hurry and the working days are significantly limited. This character also means that the annual energy performance of a building, the so-called E-value and energy certificate inspections, is out of the reach because of the limited time resource.

In cost-optimal calculations for the renovation of apartment houses the review period applied is 30 years and in other buildings 20 years (Ministry of the Environment 2013a, p. 28). Due diligence does not take sides in renovation excluding cases in which the customer wants to renovate the building or change the purpose of its use. The main influence for energy efficiency perspective is building services which come to the end of their technical lifecycle and need replacement. These systems are defined in LTP and in this thesis only systems mentioned in LTP are processed as potential energy efficiency improvements. LTP is done for next 10 to 15 years so thesis uses this as a review period for fixed costs. For the payback periods, we use the 30 year period. As an alternative for the customer, this thesis also gives an option to improve the old system and see what the influence in energy consumption is to be achieved e.g. when installing a better ventilation to the building.

In the calculation of the energy performance and consumption, this thesis uses the new nearly Zero Energy Building (nZEB) regulations as much as it is possible. This is because of the new national building code which is still under round of comments and scheduled to be validated as a new building code in 2017 or 2018. This degree only concerns new buildings, but it gives good basic lines for upcoming regulations concerning renovations. In cases when the use of the new nZEB regulations is impossible, the thesis and calculations use the degree given by the Finnish Ministry of the Environment 2013. The degree set minimum requirements for the energy performance of buildings in case of licensed renovation, changing the purpose of use or renewing technical systems of existing buildings.

In this thesis, case studies are made to test the new concept. The case buildings are located in Helsinki metropolitan area and they are apartment buildings. One from the late 1930's which has been renovated once during its lifetime and the other from the beginning of 1980's which has not had a general renovation.

1.4 Structure of the Thesis

This thesis work consists of literature review, the introduction of the new energy service as a part of due diligence and the test part of the new energy service. At first, the thesis introduces due diligence which is specified as a part of real estate due diligence. Next, the thesis discusses energy efficiency of the buildings and the lifecycle of real estate as well as the possible rebound effect of the energy efficiency actions.

Then the thesis introduces the methods used to precise the long-term renovation plan. This chapter of the thesis introduces the different kinds of methods in Finland that are used to evaluate the technical value, lifetime and conditions of a building and its technical equipment. Introduced methods are also used to compose LTP to the customer. The used methods are building energy audit, energy performance certificate, condition assessment, and maintenance manual.

At the second part of the thesis, the new energy service and the methods used in the new energy service are introduced. Also the procedure before and after visiting the site and the work after the field survey is introduced. Then the calculation tool and reporting are introduced and the methods of the energy efficiency potential analysis that we use in the thesis are going to be uncoupled.

At the last part of the thesis, the tools and the new service methods are tested in case studies, which is taken in apartment buildings located in the Helsinki metropolitan area and analyse how well the tool and the template fit to their purpose in a real life case and as a part of the technical due diligence reporting.

2 Due Diligence

Due diligence refers to an investigation that an investor conducts when planning a larger project for example developing a real estate or when planning acquisition of a property. DD can be considered as a risk management tool which tries to discover the necessary information to evaluate the risk of investment. On the other hand, Oxford English dictionary 2015 defines due diligence concept as “A comprehensive appraisal of a business undertaken by a prospective buyer, especially to establish its assets and liabilities and evaluate its commercial potential.” In the Finnish language, the term due diligence does not have a direct translation. In Finnish, DD is defined similarly as above.

Brueggeman and Fisher (2011, p. 421-423) have listed some major due diligence considerations for a potential investment property that are presented in Table 1. From the table, it can be seen that DD can involve a large amount of considerations which vary on the focus and depth of the different aspects.

Table 1. Content of Due Diligence analyses (Brueggeman and Fisher, 2011, p. 421-423, Adopted from Kohonen, 2015)

SECTION	DESCRIPTION
Rent Roll Analysis	Assess the rent and tenant information such as payment history, arrears, creditworthiness, bankruptcies, and possible disagreements between tenants and landlord.
Lease Agreements	Review of the contents of leases and amendments, possible options, responsibilities, and calculation of expenses. Some specific issues to watch include e.g. first refusal rights, the term of notice, parking, permitted uses, future improvements, and rights to sublet.
Service and maintenance agreements	Analysing the maintenance and service history to find out frequency and extent of any problems with the building, equipment, and the repairs undertook. Warranties of the equipment should also be reviewed.
Pending or threatened matters	Possible issues might include condemnation proceedings, tax suits, governmental litigation and private lawsuits
Title and deed	Review title and deed documents for e.g. easements that may affect the value of the property. Check also possible liens due to e.g. unpaid taxes, disputes over payments to suppliers and contractors and civil judgments against the current property owner.
Property survey	Examine the location of the buildings and other improvements (e.g. parking) on site, driveways, infrastructure interfaces, waterways, etc. to ensure there are no violations of any legal boundaries or site restrictions.
Government compliance	Ensure that the current or intended use of the property is allowed by zoning and building permits (e.g. allowed floor area, height limitations, parking ratios, setback lines). Also, ensure that the property and the activities are in compliance with the environmental, safety, accessibility and other regulations.
Physical inspection	Analyse the physical condition of the structures, equipment, and systems to determine possible needs for repairs and replacements (and if these are covered by warranties). The analysis should also produce a cost estimate for the required repairs and improvements.
Tax matters	Review the different tax payments, possible tax abatements, and the tax value of the property and assess the different aspects that might affect these in the future.
Insurance policies	Review the insurance coverage of the current owner, possible denials of insurance, as well as claims history of the property to assess the need for different insurance policies and to anticipate different liabilities and claims that may occur.
Engineering studies	If the physical inspection reveals needs for more detailed surveys on e.g. structures or technical systems, appropriate studies should be undertaken by qualified professionals to assess the possible implications.
Market studies	Analyse the local market conditions and trends to evaluate whether the property is able to maintain the existing tenants and attract new ones in the future. Another key consideration will be whether the property is going to be easy to resell in the future and at what price (i.e. liquidity).

The major objective of due diligence is to find worst-case problems with the acquisition property. When problems are discovered there should be a strategy how to mitigate any significant negative aspects that might affect the investment. If problems are found, there should also be a solution to the problem, or if not, the solution to the problem is inadequate and the transaction should be terminated. Due diligence survey may also discover new information that the seller or buyer would not permit until the subject is completed or investigated satisfactorily, so that the discover have a permitted solution. (John McMahan, 2006, p. 111-113)

2.1 Real Estate Due Diligence

When this thesis talks about DD, it means Real Estate Due Diligence (REDD), which means an evaluation procedure for a property before or after the acquisition. Properties are a complex subject that may contain various kinds of defects from legal, financial, technical and environmental aspects. The ignorance of defects is considered as a transaction risk. For the investor, the real estate due diligence reports are valuable source of information about the property. (Roulac, 1995, p. 734)

The basic idea of real estate due diligence is to present the possible risks that showed up in the investigation and what findings are good to take into account while considering an investment. In real estate, the due diligence is also a risk management tool, which function is to itemize and analyze potential risks. (Brueggeman & Fisher, 2008, p. 385-387)

Real estate due diligence has a major role in any real estate transaction regardless of the property type. In every case, the transaction object is a building and in most of the cases also a property. According to Rajakallio (2001, p. 17): “Properties are legal, financially, technically and environmentally complex objects that may contain various kinds of defects. The ignorance of defects is considered as a transaction risk.”

Shown in Figure 4, is the basic advantage that a good REDD study gives either to the vendor or to the acquirer of the real estate.

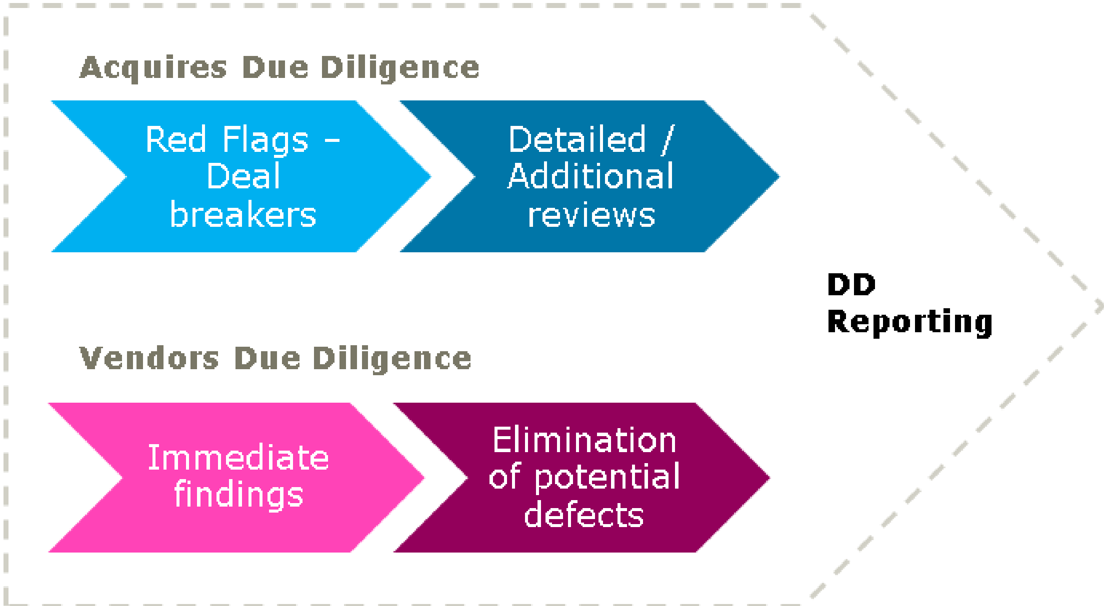

Figure 4. Due diligence process (Ramboll Finland Oy, 2016)

A detailed real estate DD study is ample and usually requires a visit to the property. According to Rajakallio (2001, p. 22), the study covers technical, financial, legal and environmental due diligence. In Figure 5, the structure of an ample real estate due diligence study is shown.

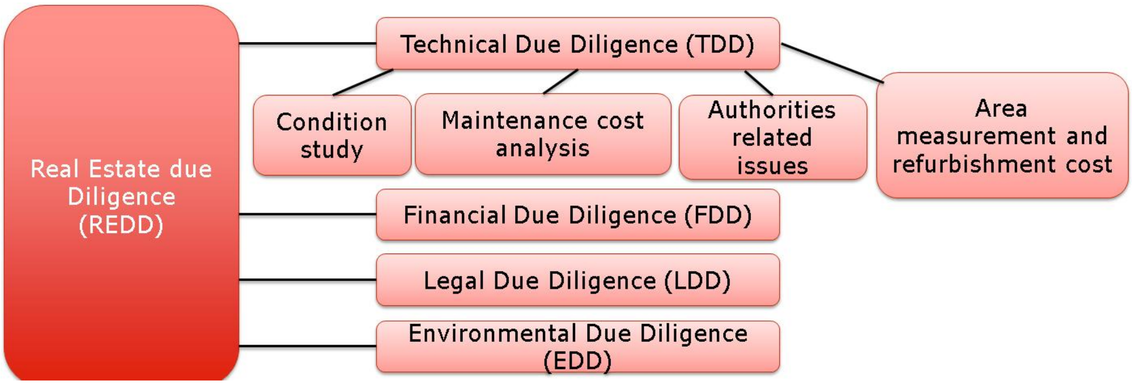

Figure 5. The structure of real estate due diligence study (Rajakallio, 2001, p. 22)

In the following chapters, the specific types of the real estate due diligence are introduced.

2.2 Financial Due Diligence

Financial Due Diligence, FDD, is typically divided into two parts: Real estate economics and financial analysis (accounting or auditing) due to the special financial nature of the properties. The primary duty of an expert in real estate economics is to evaluate the value of the real estate and recognize the subjects that can have an impact on the price of the property. This evaluation is typically done in co-operation with other DD-processes that give valid data from the real estate technical condition, possible easements and other factors that can influence the price of the real estate. Competent appraisal of the real estate should include:

1. Description of the property
2. A discussion of the economy in the region where its located
3. An evaluation of the site and neighborhood
4. Assessment of demand and competing facilities
5. Calculations of the property value including site and possible reductions as well as cost of implementing the improvements
6. A comparative analysis of the property in terms of sale prices for similar properties
7. A forecast of probable future financial performance
8. Property’s value according to composite calculations

Financial analysis depends on the real estate format. In a case where the property is sold to the customer as a real estate company, the accountant’s task is much more complex than in the case when the property is sold as an asset. If the property is sold as an asset, accountants mainly take care of the taxation which can also be performed by real estate valuer, if the valuer has the specialization on real estate taxes. (Rajakallio, 2001 p. 24-26)

2.3 Legal Due Diligence

The Legal Due Diligence (LDD) usually concentrates on issues that cannot be found on the balance sheet. LDD involves legal professionals checking the legal matters of the transaction object and evaluating the different legal aspects of the transaction. According to Rajakallio (2001), the legal matters to be inspected may involve:

- Terms and conditions of contracts
- Risks, liabilities and commitments reducing the value of the object
- Sellers conveyance right
- Trials
- The existence of network contracts
- The effect of management changes on the contracts and operations
- The existence of encumbrance certificates
- The legal state of unfinished repair projects

However, the type of transaction defines the contents of the legal due diligence. For example, companies have management and executive board that need inspecting, whereas an asset can be treated more like an object with conveyance matters. (Rajakallio, 2001, p. 26-27)

2.4 Environmental Due Diligence

Environmental Due Diligence (EDD) involves environmental issues concerning the property. In EDD process, environmental decisions, environmental licences, environmental liabilities and environmental notifications are studied. The typical risks from the environmental point of view according to Rajakallio (2001) are the toxic gasses of old waste, contaminated groundwater, and contaminated soil. Environmental impact can also come from refrigerant used in cooling equipment in the property or old gasoline or chemical stations in the plot. The implications of different issues that may be found in environmental studies may include:

- Cost of cleanup or remediation
- Liability to the public
- Dishonor after clean-up

These all may lead into significant expenses and losses of income for the property owner. (Rajakallio, 2001, p. 30-31)

2.5 Technical Due Diligence

Technical Due Diligence (TDD) is a process where all the technical issues of the property are documented, analysed and studied. According to McMahan (2006), the greatest focus of the due diligence should be in the technical area, because the mistakes in this area are the most costly to remediate. If the TDD is unsuccessful it is also the most damaging to the long-term asset value. Technical area is also the most likely thing that the seller agrees to pay for remediation, since they know they will have to do it at some point in the future, if they want to sell the property to another potential buyer. (John McMahan, 2006 p. 118-124)

The technical study normally consists the following parts: Study of the technical condition, the study of the effect of the regulative responsibilities, as well as the study of the property maintenance and operation. (Rajakallio, 2001 p. 27) Technical due diligence also intersects with the environmental due diligence and evaluates the sustainability opportunities and how the property fulfills the criteria of global real estate environmental rating systems such as LEED and BREEAM. This kind of due diligence is called Green Due Diligence (GDD). The overlapping between TDD and EDD can be seen in Figure 6.

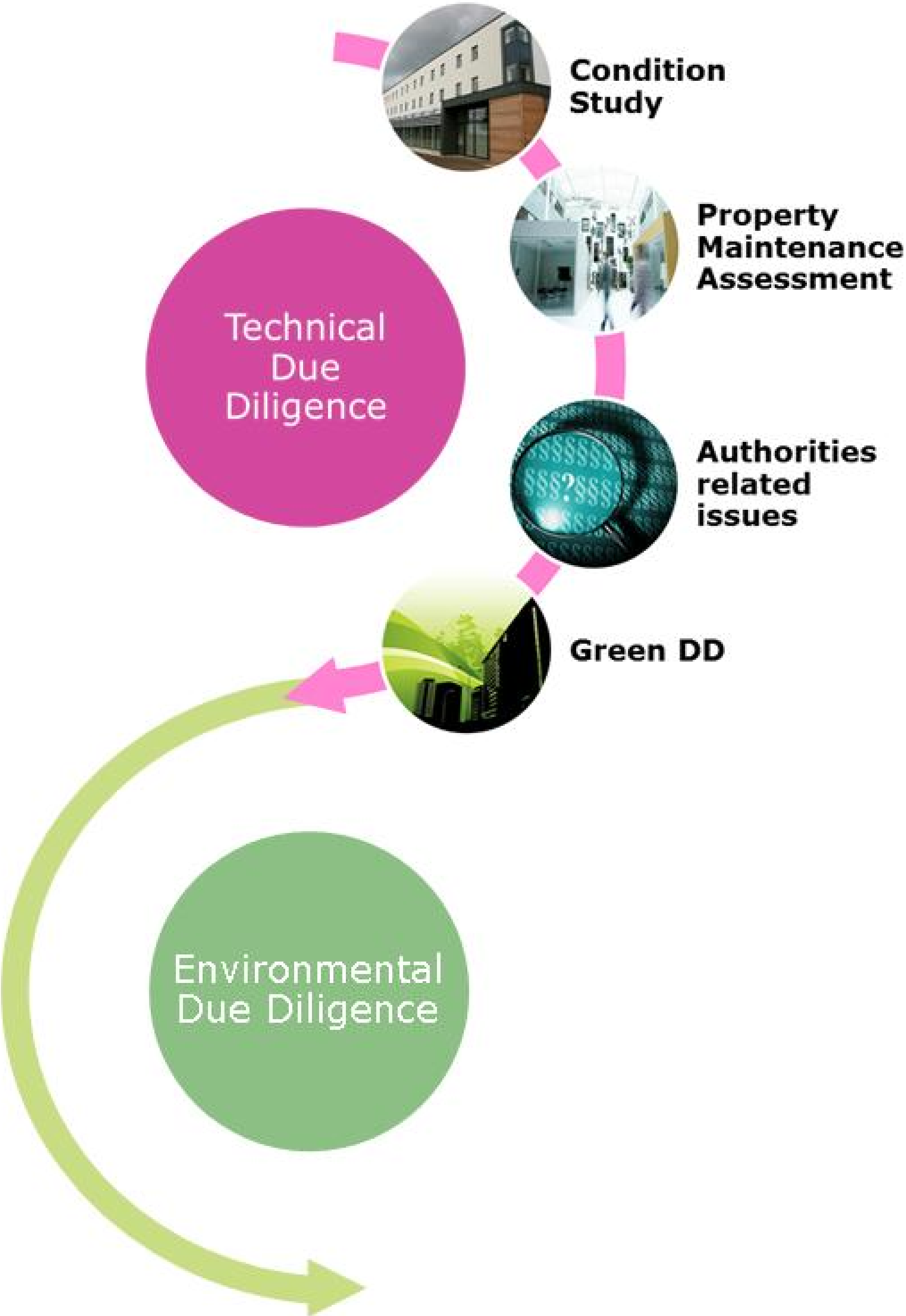

Figure 6. Intersection of Technical and Environmental Due Diligence (Ramboll Finland Oy, 2016)

2.5.1 Condition Assessment

Condition assessment is performed with an on-site audit, where the three experts in areas of structural, mechanical & automation and electrical systems, document technical details of the property and inspect the technical drawings and documents if possible. Interviews of maintenance and management personnel of the property are an essential part of the survey because they have the best available information on the conditions of property and its technical conditions. A result of the audit is a report which includes the repairs done on the property and the age and repairs of the building service technology and electricity systems. With this knowledge, experts can evaluate and schedule the future repairs and replacements of the property according to technical lifecycle, regulations and recommendations. The estimation of future repairs and replacements means an evaluation of so-called repair debt or long term repair and replacements plans. (Isoniemi 2002, s. 38-41)

The outcome of the condition assessment in technical due diligence according to Ramboll Finland Oy (2016) and Rajakallio (2001) are:

- Property's estimated repair and replacement costs for the next 10 years
- Summary regarding the technical condition (structural, HVAC and electrical systems)
- Most significant repair needs and condition risks with cost estimations divided into immediate (less than one year), 1-5 years' time span (1-5 years) and long term (6-10 years) repair needs
- Recommendations for possibly needed specific condition surveys or other further investigations

Condition studies are introduced in more detail in Chapter 4.3, of this thesis.

2.5.2 Property Maintenance Assessment

Property maintenance assessment gives estimation for the owner's maintenance costs in the future. The current maintenance organization, as well as the scope of services and their coverage, will be assessed. Their possible effects to maintenance costs are reported. The liability distribution of the lease agreement(s) regarding utilities, maintenance, repairs and major renovations is compared to the actual routine and financial statements of the property. These may differ having a direct impact on the owner's maintenance costs. The cost estimation is itemized by 13 accounts, including for instance maintenance services, cleaning, energy, water and real estate tax cost items depending on the form of the lease agreement(s). The cost items are compared to benchmarking values of similar commercial properties. Tenant's maintenance costs are excluded from this study.

The work is based on the provided maintenance and lease agreements, financial statements as well as interviews of the property manager and the accountant. The property maintenance will be reviewed on an on-site visit by the technical team. The work shall be performed by an expert specialized in real estate management issues.

The outcomes of the property maintenance assessment in technical due diligence according to Ramboll Finland Oy (2016) and Rajakallio (2001) are:

- Possible shortages in scope and coverage of maintenance contracts
- Lease agreement(s) possible soft points and deviations from current practice regarding maintenance cost liabilities between owner and tenant

- Owner's estimated maintenance cost responsibility in the resent year itemized by accounts based on the liability distribution of current lease agreement
- The second opinion of the vendor's drafted maintenance cost budget Benchmarking with similar properties and major cost differences are analyzed

2.5.3 Authorities Related Issues

The aim of the review of authorities' related issues is to highlight any possible risks or open issues regarding present city zoning, building permits and encumbrances. For instance, an insufficient number of required parking spaces or exceeded building right may cause extra costs or prevent developing or carrying out a major renovation. It is also possible that required final inspections have not been held, which may cause construction costs and issues with the insurance in case of an accident. There might also be uncovered and needed encumbrances that can be reviewed during the site visit. (Rajakallio, 2001)

The work shall be done based on all the relevant material and information available from the official records and interviews with the detail planer. The building permit records (permit documents and final inspection reports) will be provided by the customer. The realization of these authority related issues will be reviewed on an on-site visit by the technical team. The review of authority related issues will be conducted by technical expert specialized in land surveying. (Rajakallio, 2001)

The outcomes of the authority related issues in technical due diligence according to Ramboll Finland Oy (2016) and Rajakallio (2001) are:

- Realization of the most critical city zoning regulations
- Open issues regarding building permits and used building right
- Maintenance liabilities and costs of encumbrances and land leases
- Possible undiscovered and needed encumbrances

2.6 Green Due Diligence

Green DD study is based on an evaluation of building sustainability issues such as energy and water efficiency, site impacts and transport, indoor environmental quality, waste and materials. The evaluation is prepared as a part of TDD work by accredited sustainability expert.

The evaluation is based primarily on LEED for Existing Buildings (v3) or BREEAM In-Use, Part 1 (Asset) rating system. Alternatively, Green DD study can be performed based on a bespoke procedure where sustainability criteria are given by the customer (based on company's sustainability strategy/policies) or a consultant. The cost of this kind of study must be discussed separately.

The outcomes of the green due diligence in technical due diligence according to Ramboll Finland Oy (2016) and Rajakallio (2001) are:

- Summary of building sustainability issues
- Which key performance criteria are met based on current building conditions
- Statement whether or not the building is certifiable
- Proposed development measures for certification including cost estimation

3 Energy Efficiency

According to the Energy Service Directive 2006/32/EC (EC, 2006), energy efficiency is defined as "a ratio between an output of performance, service, goods or energy, and an input of energy." Energy efficiency improvement potential means a difference between the current situation and the reference situation. Reference situation can be defined as energy usage in ideal performance or a compared energy usage of the similar type of building, et cetera.

3.1 Energy Efficiency Potential

Energy efficiency potential is the energy usage difference between two different situations. Typically this is the difference between the present situation and the reference situation. The reference situation can be either a good or the best available or an ideal situation. (Tuomaala, 2012)

The traditional approach to energy efficiency potential studies is according to American Council for an Energy-efficient Economy (ACEE) divided into three categories of energy efficiency: technical, economic and achievable. These three have the following definitions:

- The technical potential represents an ideal scenario which sums all energy efficiency measures that are feasible given technology limitations. The technical potential bears no consideration to technology costs.

- Economic potential represents the fraction of the technical potential that is cost-effective, which can be evaluated in several ways. Some options include the Total Resource Cost (TRC) test or, from the consumer's perspective, such as a participant's Cost of Saved Energy (CSE).

- Finally, the achievable potential represents a fraction of the economic potential that is attainable given actual program infrastructure and both societal and market limitations.

The majority of the studies utilize the TRC test to determine the cost-effectiveness when estimating economic and achievable potential savings. This is also the perspective adopted in this thesis. (ACEE, 2008)

In the thesis, the comparison of energy efficiency potential is done by calculating the energy usage of the target building at the moment and comparing it to future energy usage after the chosen technical equipment have been changed as planned in the long term renovation plan done in the technical condition assessment phase of the TDD.

3.2 Energy Efficiency Potential in Building Stock

According to the International Energy Agency (IEA), 38 percent of the world's final energy was consumed and 33 percent of CO_2 emissions were caused by residential and commercial buildings in 2005. Finland is no exception in its energy consumption: Buildings consume 31 percent of all primary energy production. The share of heating is even larger than usual because of the long winter period. Heating is 70 percent of energy consumption in buildings or 22 percent in all of the primary energy. While buildings hold great potential in terms of energy efficiency, typically the actual effects take a long time to reach their potential. This is due to the inertia in the renewal of the building stock. Buildings can have a lifetime in the range of 50-100 years and each of the buildings elements are typically renovated only a few times in that time period. (IEA, 2008 and Viinikainen S., 2007)

Pekka Tuominen (2015) found a clear net benefit in his doctoral thesis from improving energy efficiency in building stock. In the Finnish building stock, Tuominen found an indication that a few percent rise in annual construction and renovation investments can decrease Finland's total primary energy consumption 5–7 percent by year 2050 compared to a baseline scenario. Tuominen also states that for other EU countries studied, typically energy savings of about 20 percent were estimated to be achievable by 2030 with cost-effective renovation investments in the building stock analysed. Tuominen states that overall, major economically sound energy efficiency potentials were identified, but the realization of these potentials is rather slow due to the limited renewal rates present in building stocks. (Tuominen, 2015)

3.3 Lifecycle

Lifecycle thinking is based on the fact that the wanted lifespan of a real estate is as long as possible with the lowest possible cost. In this case, the building services need a long technical life and building materials need to be durable. Also, the energy consumption needs to be low and maintenance cheap. The real estate should also be easy to adapt new purposes of use. All of this needs to be taken into account when making an energy efficiency potential analysis at the TDD survey. (Myyräläinen, 2008) The EU has also made regulations which encourage doing energy efficiency and lifecycle analysis. In 2008, every member country of EU, including Finland, approved energy and climate obligations, which commit every member country to reduce 20 percent of greenhouse gasses by 2020 from baseline of the year 1990. Also, energy efficiency needs to increase by 20 percent by the year 2020 from baseline of the year 1990. (Valtion ympäristöhallinto, 2012)

3.4 Lifecycle of Real Estate

In Figure 7, the lifecycle of a building is introduced. The lifecycle of a real estate property starts from the commissioning of raw-material and ends up to recycle, reuse or disposal. The other periods inside the buildings lifecycle are opened in the figure as well.

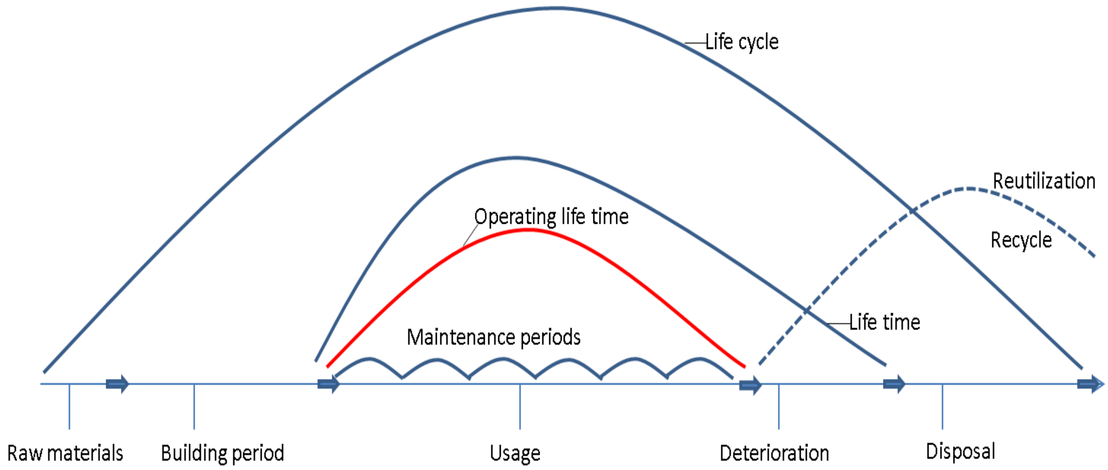

Figure 7. The lifecycle of a building (Myyräläinen, 2008).

The practical usage of the property is the most important part of a real estate lifecycle. It starts with commissioning and lasts as the structure and building elements are in a condition with nothing to complain. The planned lifetime of a property is only achieved if all the maintenance and repair work on the building is made correctly on every different element of the building as proposed in the repair plan. If the maintenance is neglected or the property goes through reconstruction the lifetime of the building can expire before the expected lifetime. At the end of a real estate's lifetime the maintenance is no more valid from an economic perspective and the property starts to deteriorate and cannot be operated as planned. Finally, the building is in such a poor condition because of the deficiency in maintenance and repairs that the building is at the end of its lifetime and it needs to be demolished. Another alternative is to use the building differently than planned after the deteriorating starts or to recycle some parts of the building equipment or materials. (Tiula, 2000; Myyryläinen, 2008)

The lifecycle of a building also includes maintenance periods of different length which mean a period of time when some kind of a maintenance procedure needs to be done again. In maintenance, the system, equipment, constituent or structure is fixed with partial renewal, repair, supplement or coating. The maintenance periods for different systems can be found from the Finnish KH-card KH-90-00403. (KH 90-00403, 2008)

3.5 The Rebound and Backfire Effect in Energy Efficiency and Consumption

There have always been critics for the energy efficiency and its consequences among the researchers. It is possible to improve energy efficiency while still seeing a rise in energy consumption. This phenomenon is known as a rebound effect. If energy consumption rises above the level it would have been without efficiency improvements the phenomenon is called the backfire effect. (Herring, 2006)

The existence of the rebound effect has been clear since Jevons (1865) hypothesized that greater energy efficiency may even lead to a backfire, where industrial energy use increases when products are manufactured cheaper. This means a situation when the price of the product comes down leading to a rise in demand which eventually raises the output and energy usage of the industry. This kind of technological rebound and backfire effect have been studied a lot and according to Sorrell and Dimitropoulos (2008) the full rebound effect can be distinguished into three different economic reactions to technological changes:

1. Direct rebound effect: An increase in consumption of goods is caused by the lower cost of use. This is caused by the substitution effect.
2. Indirect rebound effect: The lower cost of a service enables increased household consumption of other goods and services. For example, the savings from a more efficient cooling system may be put into another luxury good. This is caused by the income effect.
3. Economy-wide effect: The fall in service cost reduces the price of other goods, creates new production possibilities and increases economic growth.

In this thesis, we take into account the rebound or possible backfire effect only where the technology that has come to the end of its technical lifetime is changed and the system is upgraded from the basic level determined in the Finnish building regulations to serve for example better indoor air quality or heat balance of the building, as much as investing more in the windows with better U-value than required.

3.6 Energy Efficiency Regulations in Renovation and Rebuilding 2013

In June 2013, the Finnish directive of improving energy performance in renovations came into force. The degree set minimum requirements for the energy performance of buildings in case of licensed renovation, changing the purpose of use or renewing technical systems of existing buildings. For example, renovations that usually require planning permission or construction permit for minor construction, such as renewing technical systems or repairing external walls of the building are major renovations. Renovating existing buildings is still voluntary and the owner of the building may still decide when and to what extent to renovate the building. Furthermore, the owner of the building should also consider what the best methods are in order to improve the energy performance of the building within the limits of building regulations. (Ministry of the Environment, 2013a)

The renovation, reform and renewal of technical building systems must meet the requirements and the threshold values of the regulation of the buildings energy efficiency improvements in reform and renewal cases given by the Finnish Ministry of the Environment. This regulation gives the requirements for technical systems regarding ventilation and heating:

1. From the building's exhaust air, the heat recovered must be an amount equal to at least 45 percent of the heat required for heating the supply air or the annual efficiency must be at least 45 percent.
2. The specific fan power of mechanical supply- and exhaust air system must not exceed 2.0 kW/(m³/s).
3. The specific fan power of mechanical exhaust air system mast not exceed 1.0 kW/(m³/s).
4. The specific fan power of air-conditioning system must not exceed 2.5 kW/(m³/s).
5. The efficiency of the heating system is improved upon and, where possible with, the renewal of equipment and systems.
6. To the replacement of water and / or sewer systems, the same enactment is applied as for the new construction production.

Regarding building elements the requirements are:

1. Exterior walls: Original U-Value x 0.5, however 0.17 W/(m²K) at the most. If the purpose of the usage is changed the target U-Value is original U-Value x 0.5, however at least 0.6 W/(m²K) or better.
2. Roofs: Original U-Value x 0.5, however 0.09 W/(m²K) at the most. If the purpose of the usage is changed the U-Value is original U-Value x 0.5, however at least 0.6 W/(m²K) or better.
3. Base floors: Energy efficiency is ameliorated up to possibilities.
4. Windows and doors: The U-Value must be 1 W/(m²K) or better. Heat insulation must be ameliorated up to possibilities during the renovation of doors and windows.

These requirement limits are as strict as in new construction production. In modernization of technical systems, the new installation should be as energy efficient as possible the system or equipment is renewed anyway. As a result, the cost effects are small, if the investment is studied according to the energy savings during the entire lifecycle of the new equipment. In addition if the system is upgraded without changing the purpose of use the energy consumption can increase the same amount in theoretical energy consumption calculations. (Ministry of the Environment, 2013a, p. 34)

3.7 Energy Efficiency Regulations in nearly Zero Energy Buildings

Nearly Zero Energy Building (nZEP) means a building which is built technically in so high level that their energy efficiency and performance are at an outstanding level and their energy consumption is nearly to a zero. A significant share of energy consumed in nZEP building is produced with renewable energy sources. nZEP buildings and regulations are a result of buildings energy efficiency directive (EPBD) introduced by the European Union in 2010. The goal of the directive is to achieve the targets in energy consumption agreed on by the EU by the end of 2020. Regarding buildings, this means that every new building must be an nZEB building starting from 2021. EPBD also presents a definition of a major renovation. Member states should come up with regulation to require the improvement of buildings energy efficiency in renovations exceeding the scale of the renovation of a certain national limit. However, a major renovation is not exactly defined either and therefore space for national interpretation is allowed. (EU, 2010)

In Finland, the new nZEB regulations are under circulation of comments and they are planned to be introduced in the beginning of 2017. The new regulation concerns only new buildings and the new Finnish regulations concerning renovations are scheduled to be introduced later on in this decade. This thesis uses the new regulations as much as it can for renovations, targeting to achieve the nZEP level building by completing the renovation tasks in LTP plan as an nZEP renovations. The new regulations under circulation of comments are attached to the end of this thesis as Attachment 1. (VTT, 2013)

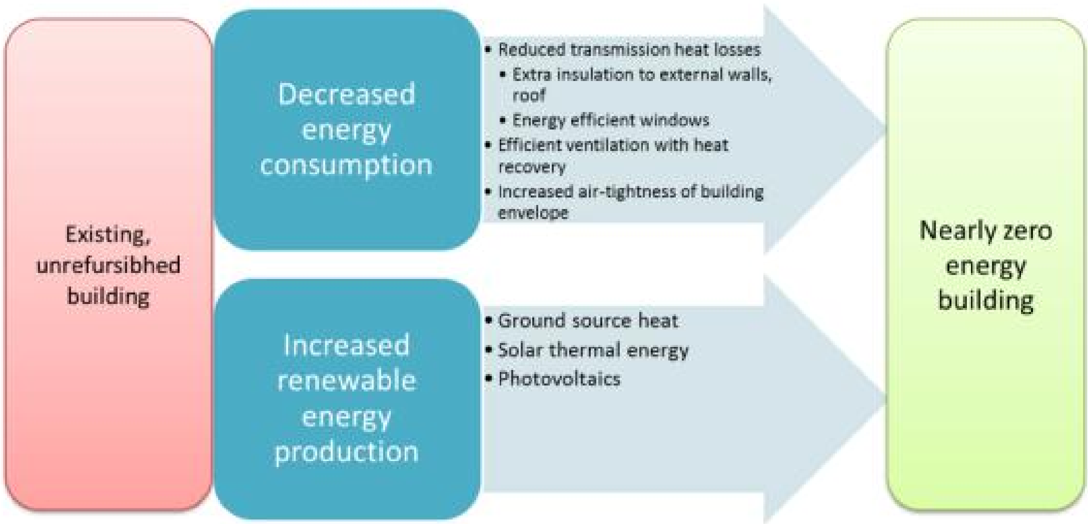

Figure 8. Nearly zero energy renovation (Adopted from VTT, 2013, p. 6)

In Figure 8, the possible nZEP renovation concept is introduced by Virtanen et al. (VTT, 2013). According to Virtanen et. al., 2013. The nZEP renovation can consist of two different parts: Decreasing the energy consumption and increasing renewable energy production. This thesis concentrates on decreasing the energy consumption.

Table 2. Finnish building regulations from 1976 to nZEB proposal (Finnish Ministry of the Environment, 2014, p. 6)

	The National Building Code regulations for different times (year→)								
R-Value [W/(m²K)]	**Before 1976**	**1976**	**1978**	**1985**	**2003**	**2007**	**2010**	**2012**	**nZEP Proposal**
Exterior wall	0.8	0.4	0.29	0.28	0.25	0.24	0.17	0.17	0.17
Roof	0.35	0.35	0.23	0.22	0.16	0.15	0.09	0.09	0.09
Base floor	0.47	0.4	0.4	0.36	0.25	0.24	0.16/0.17	0.16/0.17	0.09
Window	2.8	2.1	2.1	2.1	1.4	1.4	1	1	1
Door	2.2	0.7	0.7	0.7	1.4	1.4	1	1	1
Solid wood wall (gauge>180mm)									0.4
Base floor limited to subfloor space									0.17
Base floor limited to the ground									0.16
Other Values									
Building air tighness value (n_{50}) [1/h]		6	6	6	4	4	2	2	
Surface air tighness value (q_{50}) [m³/(m²h)]	6							4	4
Annual efficiency of the heat recovery system of the ventilation [%]	0	0	0	0	30	30	45	45	55
Air change rate (1/h)	0.14								

As we can see from the Table 2, the nearly zero energy renovation is a through renovation where practically all parts of the building envelope are renovated and air-tightness is increased from the building year or from the last renovation. Also, the technical systems are updated to answer the regulations of the nZEP level. As another point to achieve the nearly zero energy building level the renovated building should utilize renewable energy sources. The renewable energy sources during renovations are out of the scope of this thesis. (VTT, 2016)

The ownership of the building is an important factor in the renovation. For privately owned buildings, it is typically not possible to make a comprehensive total renovation in one go. Total renovations are too expensive for building owners and it is not possible for the residents to live in their flats during the renovation either. This also applies for some of the company owned buildings. Companies are also keen to renovate their buildings only as a part of the long-term renovation plan and for technical lifetime reasons. Typically if the building is owned by a company which focuses on real estate markets, it is easier to plan and carry out renovations. Large building owners are also typically motivated to reach savings in energy costs even if the investment in the renovation would be large. Because of this, the energy aspects should be taken into account when making partial renovations along the buildings' lifetime. In this way it is possible to move the building towards the nZEP-level with the renovations in buildings lifecycle. (VTT, 2016)

According to a research made by VTT (2016) as an action plan for nZEB renovations in future, "the nZEB renovation -criteria should be based on the idea of long-term renovation plan of the building so that each building under nZEB renovation process should make a plan of renovations for 15…30 years. In this plan, all the coming renovations and the order of those should be presented." (VTT, 2016, p.10)

The basic approach for energy-efficient refurbishment is a step-by-step method as presented here. The advantage of the LTP is that the coming renovations can be connected to each other and combined as an nZEB level renovation. Because the funds are very limited especially in housing associations it is unfeasible to make a total renovation to nZEB level at once. To achieve the nZEB-level building it is practical to use the LTP and make one renovation at a time and finally achieve the nZEP-level building as the lifecycle of the building goes by. The benefit of nZEP renovations on the energy performance rating is demonstrated in Figure 9.

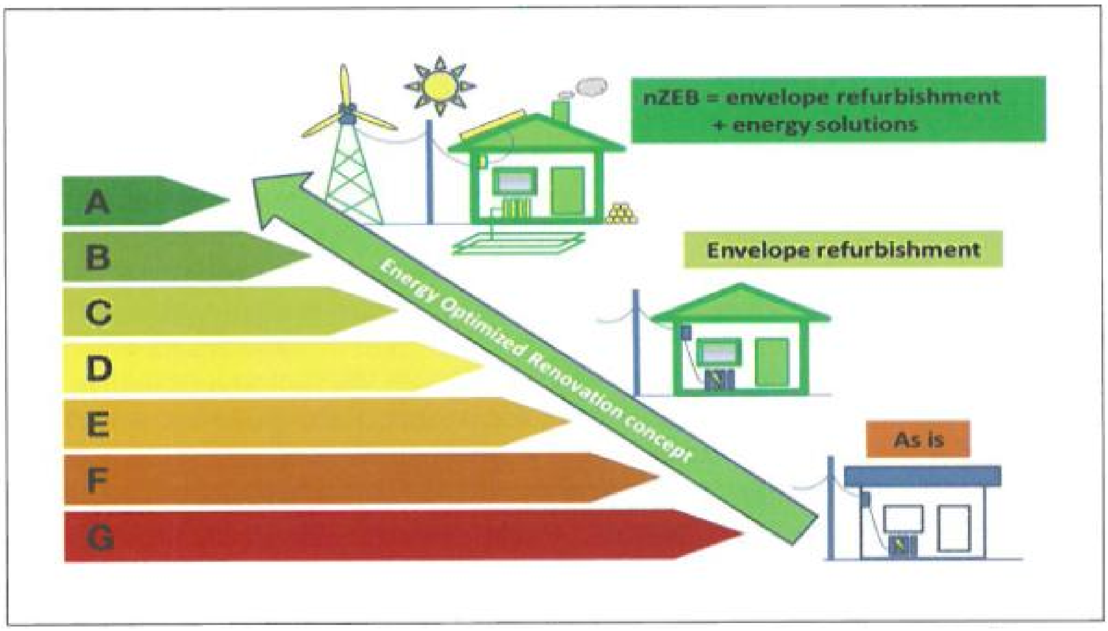

Figure 9. The benefit of the nZEP level renovations on energy performance rating (Adopted from RIL, 2015, p. 95)

In Table 3, there is an LTP example of an early 70's flat approaching the energy efficiency improvements according to the action plans presented in the LTP. The LTP plan also includes other renovation plans that are not linked into energy efficiency. Examples of these are renovations of blacktop, air raid shelters and maintenance of rainwater and subsurface drain systems. (VTT, 2016, p.10)

Table 3. Taking the energy efficiency into account in the context of residential apartment building renovations (Adopted from VTT, 2016, p.10).

Renovation	Notes for nZEB-renovation
Facade repair	Insulation is added so, that the final U-value is e.g. 0.17 W/m^2K. At the same time the building will be sealed so, that of the building, so that air leakage q50 <1 1/h
Roof repair	Insulation is added Inside or outside the U-value of <0.1 W/m^2K
Chancing the windows	Replacing the old windows with energy-efficient windows, the U-value of 0.8 ... 1.0 W/m^2K
Renovation of the heating system	Installation of exhaust air heat pump to support the heating system and added to the solar collectors.
Ventilation repair / replacement of the roof exhaust fan	Installing the heat recovery in the ventilation system heat recovery (efficiency 70 ... 80%) or installation of the exhaust air heat pump
Renovation of lighting and other electrical equipment as well as potentially whole electricity network	Energy efficient luminaires will be used with lighting control. Photovoltaic system will be added.
Water distribution system	Water meters will be installed, possibly renovation of the new heating system, heat recovery on the ventilation system (efficiency 70 ... 80%) or installation of exhaust air heat pump.

4 Methods Used to Precise the Long-Term Renovation Plan

This chapter introduces the different kinds of methods that are used to evaluate the technical value, lifetime and condition of a building and its technical equipments in Finland. Introduced methods are also used to compose the LTP to the customer. The used methods are the building energy audit, the energy performance certificate, the condition assessment and the maintenance manual. The most used method in TDD is the condition assessment, but the three others can be used as a valuable source of information while making the LTP.

In the next chapters, the introduced energy audit model is the model used by Motiva. The Ashrae model adapted to e.g. LEED certification is also included in the Motiva's model, so it is not introduced separately.

4.1 Building Energy Audit

An energy audit is an inspection, survey and analysis of energy flows, for energy conservation in a building, process or system aimed at reducing the energy input into the system without negatively affecting the output. The building energy audit applies to the mapping of energy saving possibilities of business and service buildings. For apartment buildings there is also an own building energy audit model. For large companies the energy audit is obligatory and the subsidy payments is available only for public-sector and small and medium-sized enterprises. (Motiva, 2015) In commercial and industrial real estate, an energy audit is the first step in identifying opportunities to reduce energy expense and carbon footprint. Finnish Motiva describes the steps of energy audit as: "On the basis of the data on energy use and a thorough examination of the building, wasted energy consumption is found out and worthwhile energy-saving measures are determined. Building Energy Audit reports deal with the present state of the facility's use of energy and water, describe the activity and use of HVACEA systems and set out the rationale for saving measures, the impact of savings and the payback period." Building energy audit is always performed by experts in co-operation with customer, with an agenda to find energy efficiency improvements that are cost-effective. (Motiva, 2015)

An energy audit process is combined into 10 phases, which are introduced in Motiva's (2015) energy auditing guidelines. Different phases are introduced in Figure 10

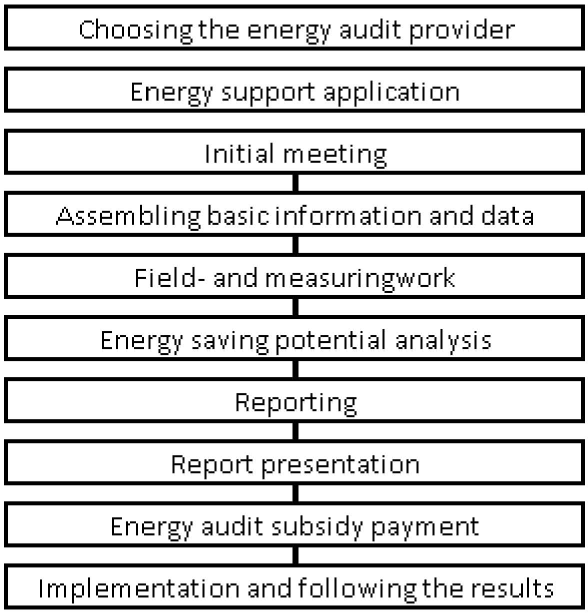

Figure 10. Phases of Energy audit process(Adopted from Motiva, 2015)

The energy audit project starts with choosing the energy audit provider according to for example bidding of the service or the expertise of the provider. At this phase a suitable energy audit model is chosen to the target building according to the type of building, cubic content, energy consumption and the objective of the energy audit, concentrating to service, industry or energy sector (Motiva, 2015, p. 15). When the energy audit model is selected the customer, usually with the assistance from the provider, delivers an energy support application to the Centre for Economic Development, Transport and the Environment (ELY Centre) before the project starts (Finnish Ministry of Employment and the Economy, 2016). After the application is returned to the ELY Centre, the contract between the customer and the provider of an energy audit can be signed. (Motiva, 2015)

Energy audit always starts with an initial meeting where the schedule, focusing and other significant aspects are discussed and agreed on. According to agreements made in the initial meeting, the auditors familiarize themselves with the basic information of the building to achieve a basic understanding of the building and its energy economics. This information is for example 3-5-year-old energy and water consumption information, HVACEA drawings and inspections or reports made to the building. When the auditors have made themselves familiar with the basic data, they do field and measuring work at the site. During the field work, the maintenance staff and users of the building are interviewed about the conditions of the building. Also, water, heat, electricity and fuel consuming objects and systems are studied over the field study. The possible energy saving potential and focus are decided during the survey based on expert's findings and measurements. After the field study, the energy auditors analyze the measurements and findings to determine the energy savings action list, which has a payback period of fewer than ten years. (Motiva, 2015; Myyräläinen, 2008)

The energy auditors present the results of the energy audit in the inspection report, which is documented according to the instructions given by Motiva. The report layout is dense and plain. The energy saving action plans are presented in the report as a table and consumptions of heat, water, electricity, cooling and fuel are presented as pictorial diagrams and figures. In the report, the cost estimation of the action plans, the payback periods of the actions, influence to energy and water consumption and their savings and to the volume of carbon dioxide are presented clearly. When the energy audit report is ready, the final version of the report is presented to the customer. The findings and action plans are demonstrated to the customer and the approved tasks are listed with the customer for further action. After the delivery of the energy audit report, the auditor, the user and maintenance staffs of the audited buildings go through the new actions concerning energy economics. The actions that produce energy savings can be for example new set points, equipment's and pre-timed controls.

For completion of the energy audit, the customer delivers the order payment for energy audit subsidy payment to the ELY Centre. The order payment includes the outcome of final funding and cost performance of the project. In the last phase of the energy audit, the auditor controls and supervises that the actions approved and reported are implemented in the building. (Motiva, 2015)

The daily per capita consumption of heat and electricity determined in the energy audit can be benchmarked to other buildings in the tertiary sector and their median specific consumption. These medians are based on Motiva's energy audit database, which has information on the specific energy consumption of almost 7000 energy audited buildings on the sector between years 2009-2014. (Motiva, 2016) When benchmarking with Motiva's information, it is wise to remember that all buildings are unique and with the median of daily per capita consumption, the energy efficiency potential comparison is not so detailed because the benchmarked buildings are not listed by building years or area and there is no information available about the technical solutions. In Table 4, the energy saving potentials for different building types are introduced. In the table, the average payback period for the investment is 2.9 years with a variation of 0-6 years depending on building type. (Motiva, 2015) The most typical saving proposals for the buildings have been according to Motiva (2015):

- Reduction of the inside temperature
- Adjustment of the heating network
- Adjustment of the heating of the air conditioning
- Adjustment of the running times of the air conditioning
- Attaching heat recovery to the air conditioning network
- Limiting the flow of the plumping fixtures
- Adjusment of the lighting or change of the lighting fixture

Table 4. Percentual saving potentials by building type between years 2009-2014 of the energy audited buildings in heat, electricity and water (Adopted from Motiva, 2015)

Type	Classification of Buildings (Statistics Finland 1994)	Objects		Volume (1000 rm^3)				Saving potentials [%]		
		(Object)	%	Object	Average	Max	Min	Heating	Electricity	Water
C Commercial buildings										
11	Wholesale and retail trade buildings	594	6.0 %	30 384	51.6	1069.0	0	14	6	5
12	Hotel buildings	201	2.0 %	6 204	32.7	147.2	0	19	10	6
13	Residential buildings for communities	83	0.8 %	806	9.8	72.5	0.7	10	5	2
14	Restaurants and other similar buildings	81	0.8 %	243	3.4	25.8	0.3	32	25	3
C	**Sum**	**959**	**10 %**	**37 637**				**17**	**7**	**5**
D Office buildings										
15	Office buildings	1302	13.3 %	45 871	35.8	632.6	0	19	4	6
D	**Sum**	**1302**	**13 %**	**45 871**				**19**	**4**	**6**
E Transportation buildings										
16	Transportation buildings	204	2.1 %	5 543	28.6	250.0	0	19	20	6
E	**Sum**	**204**	**2 %**	**5 543**				**19**	**20**	**6**
F Buildings for institutional care										
21	Health care buildings	483	4.9 %	16 599	35.5	504.5	0	16	8	6
22	Social welfare buildings	277	2.8 %	3 034	11.4	101.7	0	13	7	8
23	Other social service buildings	866	8.8 %	2 915	3.9	78.8	0	15	1	9
F	**Sum**	**1626**	**17 %**	**22 548**				**15**	**3**	**7**
G Assembly buildings										
31	Theatres and concert halls	46	0.5 %	1 780	39.5	132.5	0	14	6	9
32	Libraries, museums and exhibition halls	164	1.7 %	2 187	14.2	532.0	0.7	16	14	7
33	Association and club buildings, etc.	158	1.6 %	1 141	7.6	47.3	0.2	30	18	12
34	Buildings of religious communities	183	1.9 %	1 440	8.0	50.9	0	21	13	9
35	Buildings for sports and physical exercise	320	3.3 %	9 207	30.5	262.0	0	18	11	6
36	Other assembly buildings	40	0.4 %	713	18.8	157.0	0.5	30	4	1
G	**Sum**	**911**	**9 %**	**16 468**				**19**	**11**	**6**
H Educational buildings										
51	General education buildings	1630	16.6 %	23 784	15.6	123.2	0	16	5	6
52	Vocational education buildings	282	2.9 %	9 134	34.1	188.9	1.0	9	6	4
53	University and research institute buildings	40	0.4 %	1 620	45.0	215.0	1.3	22	9	8
54	Other educational buildings	36	0.4 %	551	17.2	92.3	1.4	14	15	7
H	**Sum**	**1988**	**20 %**	**35 088**				**15**	**5**	**6**
J Industrial buildings										
61	Buildings for energy supply, etc.	277	2.8 %					17	8	39
62	Chemical industry buildings	128	1.3 %					24	1	2
63	Metal industry buildings	301	3.1 %					4	16	0
64	Food processing industry buildings	209	2.1 %					24	8	3
65	Wood industry buildings	106	1.1 %					26	8	3
66	Glass, ceramics and rock industry buildings	196	2.0 %					8	6	10
67	Paper pulp and paper industry buildings	173	1.8 %					0	0	0
69	Industrial production buildings	455	4.6 %					15	5	5
J	**Sum**	**1845**	**19 %**					11	9	1
K Warehouses										
71	Warehouses	104	1.1 %	7 396	74.0	572.64	0	21	7	7
K	**Sum**	**104**	**1 %**	**7 396**				**21**	**7**	**7**
L Fire fighting and rescue service buildings										
72	Fire fighting and rescue service buildings	141	1.4 %	1 667	12.4	88.75	0	24	8	8
L	**Sum**	**141**	**1 %**	**1 667**				**24**	**8**	**8**
M Agricultural buildings										
81	Livestock buildings	2	0.02 %	50	24.8	40.0	9.5			
89	Other agricultural buildings	17	0.2 %	942	55.4	317.8	0.5			
M	**Sum**	**19**	**0.2 %**	**992**						
	Other building type or type unknown	727	7.4 %	16 087						
Sum total		**9 826**	**100 %**	**189 297**				**12**	**7**	**1**

4.2 Energy Performance Certificate

Energy Performance Certificate (EPC) is a result of European Union Directive 2002/91/EC related to the energy performance of buildings. The energy survey needed to produce an EPC is performed by an assessor who visits the property, examines key items such as the air conditioning, walling insulation, radiators, heating system, windows, and so on. The EPC is an official document representing buildings energy efficiency on a scale from A to G. Furthermore, it gives suggestions on how to improve the energy efficiency of the target building. Category marked in the EPC has to be declared when selling or renting the building. (Ministry of the Environment, 2013) The EPC is also demanded for new buildings when a building permit is applied. The exception cab be made according to energiatodistus web page administered by Motiva, to buildings that are temporary, are used categorized as a holiday home, have an area less than 50 m^2, are defined as listed buildings, are Churches or buildings of religious communities, are owned by the defense administration or are listed as a building type that goes through a lot of problems if the EPC is applied to them. These kinds of buildings are for example glasshouses and shelters. (Energiatodistus, 2013; Motiva, 2016; Ministry of the Environment, 2013)

An energy performance certificate is valid until it is replaced by a new EPC or until 10 years after granting at the most. (Ministry of the Environment, 50/2013 8 §) The energy performance rating discloses the theoretical or in another words calculated energy used for heating and cooling and also the consumption of electricity specifically delivered energy used by the building and the buildings services such as air conditioning. This gives the building its E-value$\left[\frac{kWh}{m^2}\text{ a year}\right]$. The E-value represents a building's annual consumption of purchased energy according to the heated net interior area and based on the standard use of the building type and weighted coefficients of the energy carriers used. The value determines the energy efficiency class, which the building obtains. The best and the tiniest energy consumption class is A, and the biggest energy usage is at class G. In Table 5, the energy efficiency ratings for different building types in Finland are shown.

Table 5. Energy efficiency ratings for different building types in Finland. (Ministry of the Environment, 2013, Attachment 2, p. 1-5)

	Energy performance rating [kWh/(m² a)]						
Building type	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Small Detached house <120m²	≤ 94	95-164	165-204	205-284	285-414	415-484	485 ≤
Big Detached house > 600m²	≤ 70	71-106	107-130	131-210	211-340	341-410	411 ≤
Terrace houses	≤ 80	81-110	111-150	151-210	211-340	341-410	411 ≤
Multi-storey buildings	≤ 75	76-100	101-130	131-160	161-190	191-240	241 ≤
Office buildings	≤ 80	81-120	121-170	171-200	201-240	241-300	301 ≤
Commercial building	≤ 90	91-170	171-240	241-280	281-340	341-390	391 ≤
Accommodation building	≤ 90	91-170	171-240	241-280	281-340	341-450	451 ≤
Educational buildings and Nurseries	≤ 90	91-130	131-170	171-230	231-300	301-360	361 ≤
Sports cente excludinf swimming and ice-halls	≤ 90	91-130	131-170	171-190	191-240	241-280	281 ≤
Hospitals	≤ 150	151-350	351-450	451-550	551-650	651-800	801 ≤

The purpose of the E-value is not to describe the true energy consumption. Instead, it functions as a key indicator in energy use, defined by certain rules. In the E-value indicator, the calculated purchased energy used by a building is multiplied with energy source-specific coefficients that describe the consumption of primary energies. The E-value indicator can be used in new constructions to influence, among other things, the shape of the building, the design of window and door openings and other characteristics and energy forms used. The same building can have several E-values for different parts of the building if the building has several purposes e.g. office – business premises and if these different operations cover more than 10 percent of the heated net interior area. This also means that the same building can obtain multiple energy perform ratings depending on the building type and rating borders of the current building type. (Ministry of the Environment, 2013)

4.3 Condition Assessment

The maintenance of a real estate should be performed systematically with technical control and the maintenance process execution should be carried out as economically as possible. The process runs fluently if the current condition of the property is well known and the future repairs and maintenance task and their schedule and approximate costs are known. Condition assessment gives an impartial view of the current condition of the property and upcoming repairs and of the required further studies about the condition of the property. The purpose of condition assessment is to describe the technical condition of the building and to collect basic information about the property and with this information compile the long-term renovation plan (LTP) for the building. The condition auditor’s opinion about the building technology is introduced in condition assessment report and also, the compilation LTP is added as an attachment to the report. The typical procedure for the condition assessment for residential buildings is introduced in Finnish KH-card 90-005355, which also specifies instructions for good practice in condition assessment surveys in residential buildings.

The technical lifetime of building technology is forecasted based on research and practical knowledge of expectations of operating lifetime of devices, systems and building elements. Technical and economic lifetime, especially in HVAC-systems, does not go hand in hand. The economic lifetime can be much shorter than the technical because of the improvements in technology. For example, the older equipment can use much more electricity than the new, or the maintenance and operation cost can exceed the level of it being more efficient to change the older equipment than to keep it to the end of its technical lifetime. Technical lifetimes of the building, its equipment, systems and elements are specified in Finnish KH-card called *Kiinteistön tekniset käyttöiät ja kunnossapitojaksot* (KH 90-00403, 2008). In Figure 11, an example of the card is shown. The real lifetimes can vary a lot depending on the stress load, environment and operating time of the system. (KH 90-00403, 2008)

Identifier	Heading, definition	Typical building decade and other specifications	Average technical lifetime Year (R= building age, J= system age)			Planned maintenance operations		Notation
			stress class 1 hard	2 normal	3 light	Inspection period Year	Maintenance/up-keep period Year	
2	**Building services engineering**							
21	**HVAC-systems**							
	HVAC-part with TalotekniikkaRYL 2002 names applied							
G1	**Heating systems**							
G11	**Heat distribution**							
G1110	District and area heating							
G1111	Heat distribution centres					12mm, when age is <10 a 4 mm, when age is 10…20 a 1mm, when age is >20 a		The technical lifetime of the heat distribution centre is handle as a complex.
G112	Heat exchangers							The inspection period depends of the age of the heat exchanger.
	Acid-proof plate heat exchanger with brazed jointing			20				
	Heat exchanger with copper pipes	…2000		20				
	Plate heat exchanger with rubber joints	…1990		10			Tightening of bolts and change of seal	
	Heat exchanger with steel pipes	…1990		20…30				
G1120	Oil heating							
G1121	Oil tanks					12mm, when age is <10 a 4 mm, when age is 10…20 a 1mm, when age is >20 a	Removal of condensate water	Rule KTMp 344/1983. The inspection of the oil tank musat be ordered from licenced provider. The shielding pools of the oil tanks musat be inspected regularly.
	Oil tanks, plastic, inside	1980…		50				
	Oil tanks, plastic, ground	1980…		40				
	Oil tanks, steel, inside	…1990		40			Less than 15 a, cleaning	Condens water hazard. Water and contaminant inside the tank can create corrosion inside of the tank.
	Oil tanks, steel, ground	…1990		20			Less than 15 a, cleaning	
	Oil tanks, steel, ground in concrete bunker	…1990		30			Less than 15 a, cleaning	
	Oil tanks, steel, outside	…1980		40			Less than 15 a, cleaning	
G1122	Pipes and installations							

Figure 11. Technical lifetimes (KH 90-00403, 2008)

TDD studies give a good view of the upcoming investments in the property, because of the long-term estimation. This kind of plan can be used almost directly to cash flow analysis, so it is a good fit for the appraisal report. In Figure 12, an example of a long-term estimation made for a 10-year scope can be seen.

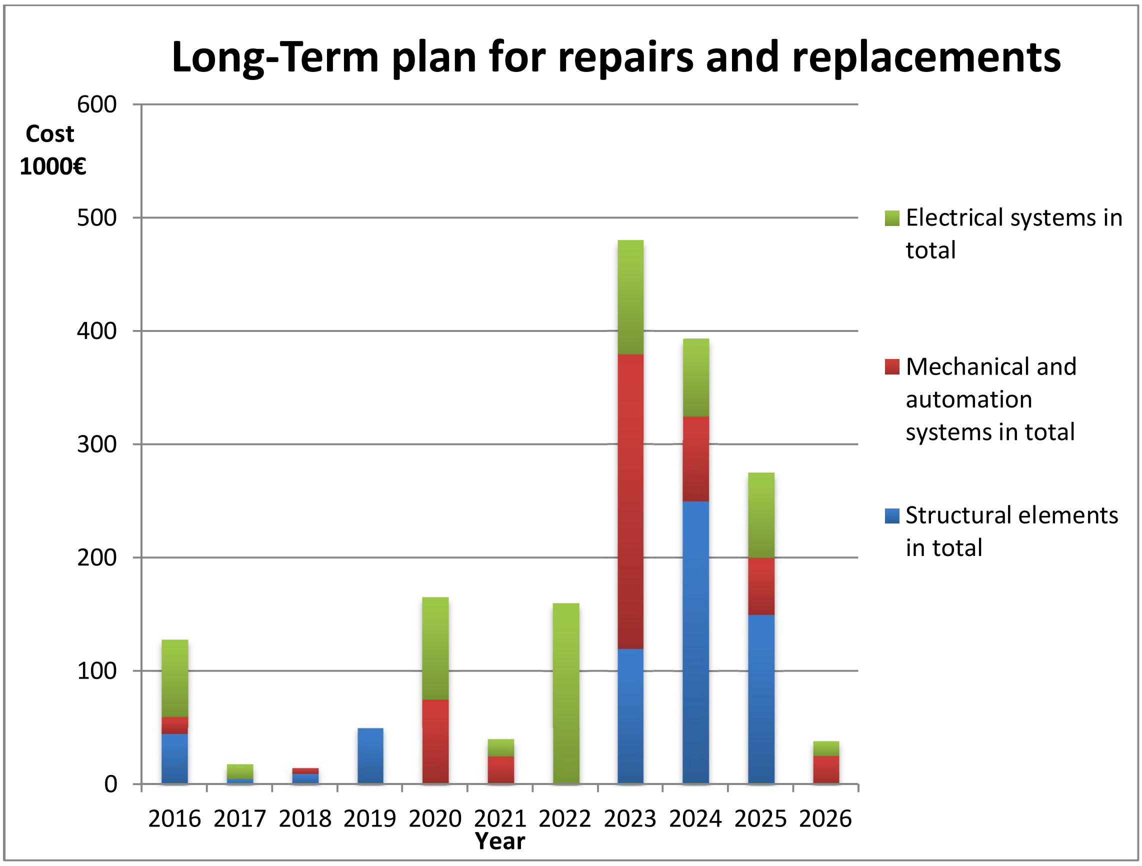

Figure 12. An example of a long-term estimation for costs of repairs and replacements

In Figure 12, all the technical components are divided into separate expenses for each year with a 10-year scope so that in the first column are the expenses that should be done immediately. The expenses in the first column are undone repairs that have not been implemented within the technical lifecycle of equipment or the normal repair cycle. These undone repairs are the reason why the property has a repair debt. The rest of the planned repairs are based on the condition of the system and technical lifetimes according to KH 90-00403. (Rajakallio, 2001, p. 27-29)

4.4 Maintenance Manual

The national building code section A4 compiled by Finnish Ministry of the Environment 2000 require that new constructions and buildings under renovation must be equipped with a maintenance manual if the buildings are inhabited or used as a permanent working place. This code does not apply to buildings that are temporary or used as a holiday home. Also, warehouses or production buildings without permanent occupation are out of the maintenance manuals scope. (Ministry of the Environment, 2000)

The typical content and important functions of maintenance manual are presented in Figure 13. From the figure, we can see that the maintenance manual is a complete information database of the real estate and building. Basic data about the real estate and building is found in one place and also, the maintenance documents are added to the manual. Maintenance manual is a good tool to manage the lifecycle of real estate especially when the maintenance manual is compiled with high standards. It can help to achieve the best available energy efficiency, indoor climate, and regular maintenance is done both effectively and with best practices. A high standard maintenance manual consists of at least basic data of the real estate, services and interfaces, maintenance data, real estate management information, real estate documents, reports and upkeep. (Partonen, 2016; Myyryläinen, 2008)

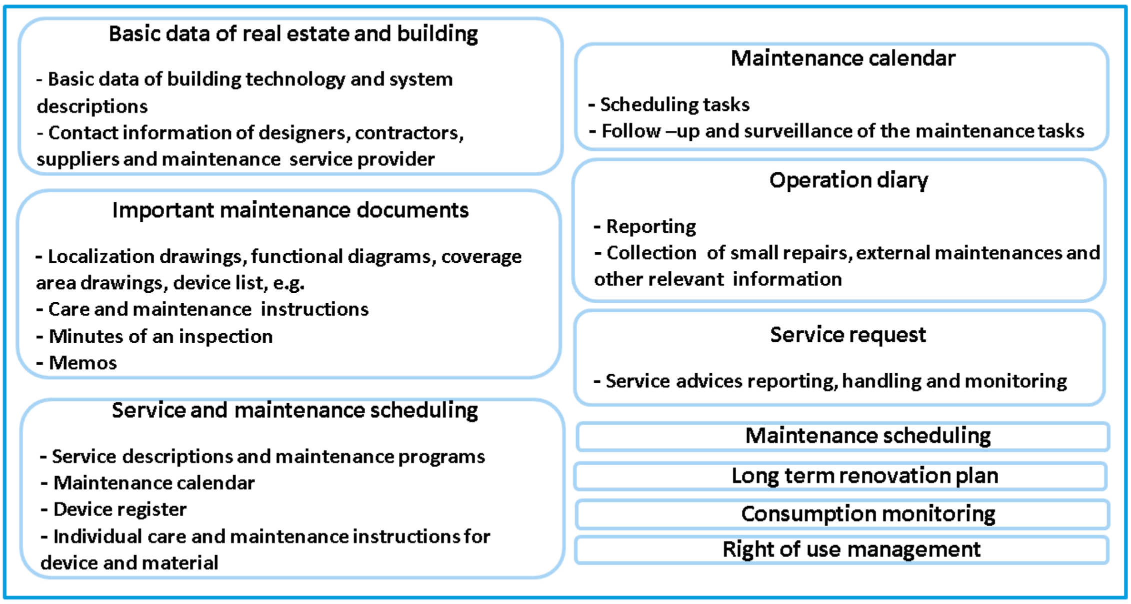

Figure 13. Maintenance manuals typical content and important functions (Partonen, 2016)

Good upkeep of maintenance manual is an important factor in real estate management and it ensures that all the information is found and documented properly when e.g. the maintenance company changes or a new supplier comes with a new course of action. It also helps the new contractor responsible for the maintenance or upkeep of the building when the responsibility of the real estate changes from person to other. (KH 90-40041, 2005) Maintenance manual can be an electrical application, paper folder or both. Electrical maintenance manual is easier to update and more efficient when the owner needs to handle with several properties. Still many users also want the paper file alongside the electrical, because it is viewed as easier to handle on site. (Partonen, 2016)

The importance of updating and developing the maintenance manual is critical because the manual is only valid as long as nothing happens or changes in the property in terms of technical and operational view. Especially in office and commercial buildings the changes in the type of use are typical and the building technology is changed to serve the new type of usage. In these cases, the updating of maintenance manual becomes a topical issue. Changes in for example, equipment's running hours or adjustments and possible new devices should be added to the maintenance manual, to archive the old information and to update the new information to the maintenance manual. The liabilities to update and develop the maintenance manual are customers, who can also place a responsible organization to the task. The responsible organization is typically a company that additionally makes the maintenance and administration of the property. Often the maintenance company is in a major role in updating the maintenance manual, which gives the owner a responsibility to supervise the subcontractor so that the updates are made as appointed. The owner has to make the updates to the maintenance manual which are outside the contract and are in owner's responsibility. E.g. when adjustment works are done on the property. (Myyryläinen, 2008; Partonen, 2016)

5 The Concept of the New Energy Service as a Part of Technical Due Diligence

In this chapter, the developed new energy service is introduced as a part of normal technical due diligence survey. The Technical due diligence survey and the new energy service is introduced phase by phase in the following paragraphs.

To do energy related calculations or estimates in due diligence in order to achieve energy saving potentials or consequences of upgrades to technical systems, a good knowledge of the condition of the technical systems in the building is needed and an estimate how much these technical systems have technical lifetime left has to be done, because typical investor does not want to repair what is not broken. So specific LTP has to be done, which gives an estimate of the cost and timing of the coming repairs, renewals and general overhauls. These needs are studied in normal DD- condition assessment supported by knowledge given by the owner and possible executed condition studies, maintenance manuals and energy surveys. The practical target of the thesis is to harness this knowledge into energy service which gives either the buyer or the owner a normative base of the possible energy efficiency and saving potential of the building when tasks are implemented according to the long term renovation plan compiled in the DD-condition survey. The new service should also answer to the question what of happens to the payback period if the equipment is upgraded to even more efficient one than the one required by the new Finnish building regulations which are under circulation of comment demand. All the new renovations are calculated as if the building would be renovated to the level of nearly zero energy building.

In this thesis, the situation is that the company has got a commission for technical due diligence for apartment buildings located in Helsinki metropolitan area. The process adopted from the technical due diligence and modified to the new energy service is introduced in Figure 14.

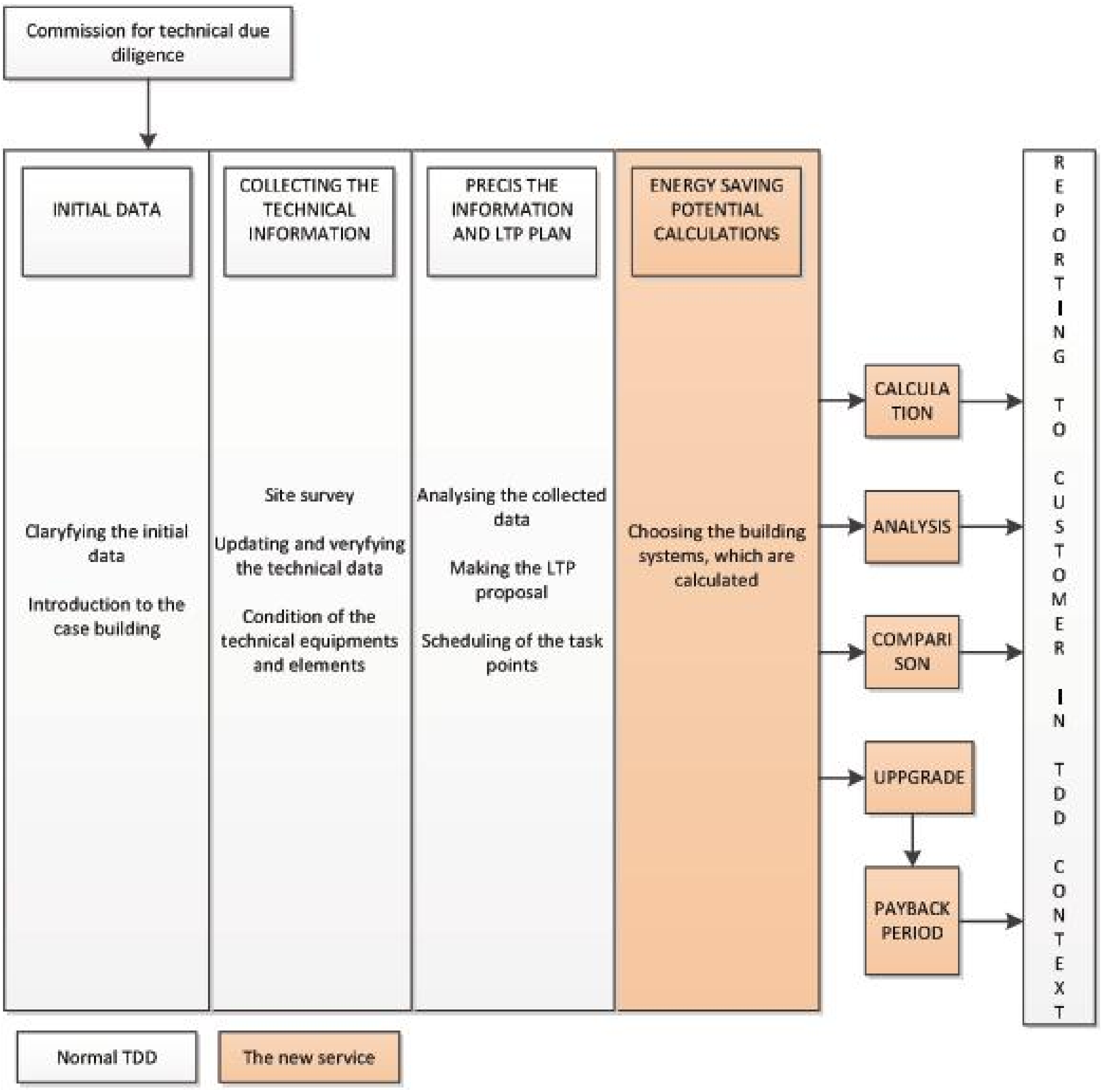

Figure 14. The process chart of the new energy service

The process consists four different phases and reporting. The first phase is to clarify the initial data before the site survey. The second is the site survey in which all the technical information is collected and verified. In the third phase, the LTP is made for the building for next 10-15 years using the information collected during the first and the second stage. In the fourth phase, it is decided which of the action plans made in the LTP are taken into specific consideration and into energy efficiency calculations. For the chosen tasks, the new service calculates the actual energy consumption as it is now and compares it to the technology that is the minimum requirement in finzeb building (Finnish Ministry of the Environment, 2016) regulations, giving as an answer the possible energy saving potential, or the rebound effect.

The goal is to achieve a quick tool to calculate and evaluate the effect of repairs and maintenance of the buildings on energy and costs. For specific building parts the effect of even better technique is calculated and the effect to the payback period of the better technology is also included to the service.

The new energy service is designed to give a better knowledge of the consequences of the future repairs, renovation and overhauls from an energy consumption and energy efficiency perspective. The service is planned to be added to Ramboll’s value adding

TDD services. Because the new service is procured with technical due diligence the service must have two different benefits or a benefit that can serve both the vendor and the buyer. The procedure of the service can be the same in both cases, but the benefit of the service can have variety depending on which side orders the new service. In the case when a potential buyer orders the service, it is typical, that they are planning to develop the building and they are keen on knowing the fixed cost of the energy and potential savings in energy in near future and they are also more willing to develop the building technology in the long run. In the case of a vendor, the development of the building and additional costs are typically overruled and they are not willing to repair anything if they do not have to. This time the service must give them selling points and benefits in negotiations to avoid disadvantages.

The new service is planned to be very flexible and able to be executed and reported in limited and tight time budget. This means that the calculation needs to be done efficiently and the modelling of the apartment building is not very detailed but still accurate enough to achieve solutions that can be used as suggestive estimations of the future energy consumption. As described previously in this thesis, the new service is coupled with the DD- condition assessment and the LTP proposal in order to evaluate the major technical risks and repair needs, which the object is likely going to meet during the following ten to fifteen calendar years, meaning that firstly the three experts in areas of structural, HVAC and electrical perform the site visit and make the condition assessment and after that the new service takes the action plans into scrutiny and selects the most realistic and earthly task under the energy scrutiny. Then starts the calculation phase where the energy saving or backfire potential of the upcoming actions is calculated. After the basic calculations, the possible upgrades to the minimum level installations are taken into consideration and the payback periods of the investments are calculated with the escalation taken into consideration. In the investment calculations the escalation is investigated with 2 and 4 percent.

The LTP actions taken into the calculation phase are the author's best knowledge, which of the tasks included in the LTP proposal will affect the energy consumption of the building the most and are not in a bigger part linked to the behavior of the tenants. These actions are calculated with the calculation tool, if it is possible, and in cases where the tool is not handy the energy consumption is calculated with a suitable simplified method to achieve some results as guideline to the customer with the investments.
The typical actions taken into the calculations are:

- Windows and external doors
- External walls and wall complementaries
- Foundation, basement walls and ground floor slab
- Air conditioning and refrigeration services
- Ventilation services
- Heating services
- Lighting systems
- Electrical heaters and other equipment

These tasks do not exclude any other task to be taken into consideration. The final combination of LTP task chosen to the calculation phase depends on the building year, technical and structural systems and the repair need based on the LTP plan. This means that if a system is not at the end of its technical life time or detectable as broken the service does not automatically take it into the calculation. Only if the customer wants the consult also to take, for example an old ventilation system into the calculation, even if it has a more technical lifetime left than the rest of the review period, the consult will do that.

After calculations, the results are implemented to the DD- report as a yearly effect to the energy costs of the building and as individual systems, so that customer can see how significant influence one task can have from an energy point of view.

When buildings technical solutions come to the end of their technical lifetime and they need to be replaced, the technology has improved and regulations have typically tightened. This makes it a difficult task to analyse the energy consumption and the fixed costs of the building in a longer period. The new energy service answers to that need and gives a rough estimate of the future energy consumption of the building.

Outcome:
- Information about the building’s energy saving potential
- Consequences of system upgrades to energy consumption
- Possibility to achieve a better E-value with LTP- actions
- Potential to grow the return of the investment with lower energy consumption

In the next five subsections, the phases of the new energy service are introduced and it is explained what will happen in each phase.

5.1 Phase 1, Introduction to initial data

The project starts with an order and after that the project team gets access to the data room of the project. In the data room, the data room coordinator adds information about the project, like technical drawings, rescue plans, floor plans, financial documents etc. At this point, the project team, which is going to do the condition assessment in phase two, introduces themselves to the initial data and to the technical systems of the building and make notes to themselves which are the most important pieces of information not provided but needed, in order to find those during the site visit.

The Finnish building regulations part A4 requires that most buildings must have instructions for the use and maintenance manuals for the buildings technical solutions. Thus there are no instructions on how to update these instructions and manuals, so most of the time there is a paucity of raw data when the project is starting or the raw data is old and it is not reliable.

This is why the technical due diligence always includes a technical site survey where three experts in mechanical, electrical and structural areas inspect the building and take notes of the current technical equipment and components.

In the new service, the introduction to the given initial data is made more energy efficiency related than in typical TDD. Typically in TDD survey the experts checks only the main technical details of the building, but in the new service, every notable improvement aspect is put in the notes of the expert for further inspection during the site visit and technical details of the buildings equipment’s are listed if founded and make sure during the site visit that the provided information is correct.

5.2 Phase 2, condition assessment

Phase two is the site visit and the condition assessment. The site survey during technical due diligence is a crucial part to achieve the best available information of the buildings present condition. The condition assessment covers the structures and technical systems which belong to the property owner. So, possible tenants' own technical installations are not included in the condition assessment, unless otherwise agreed with the customer. In the site visit, the technical manager of the owner and the person in charge of the maintenance gives the information about which equipment belongs to the tenant and which does not. In the condition assessment the methods will include sensory impressions and non-destructive procedures. During the site survey, the expert team also evaluates the energy efficient usage of the technical systems and overall energy efficiency of the building services and is there an energy saving potentials in the old systems. In the new service also the technical details of the equipment's are inspected more detailed.

The work shall be performed by three technical experts. The condition assessment covers the structures and technical systems as follows:

Structural systems:

- Building elements on plot
- Foundation, basement walls and ground floor slab
- Load-bearing frame
- External walls and wall complementaries
- Windows and external doors
- Roof elements
- Internal complementaries and surfaces

HVAC systems:

- Heating services
- Water and sewage services
- Ventilation services
- Air conditioning and refrigeration services
- Fire protection services
- Building automation systems

Electrical systems:

- Electrical services on the plot
- Distribution boards
- Installation channels
- Conductors and conductor equipment
- Lighting systems
- Heaters and other equipment
- Special electric systems, like auxiliary power systems and safety lighting
- Information system services
- Lifts and other transportation equipment

5.3 Phase 3, the condition assessment report and LTP

After the site visit, all the key findings are written down and open ended questions from the site visit are asked from the controller of the data room. Then the three experts write a report of their own technical area. The condition assessment report will consist of the elements listed below:

- Basic data concerning the structures and technical systems of the property and possible other constructions. For example a parking hall or storage area.
- Verbal summary regarding the technical condition, the most significant technical risks and
- Repair needs of structures, HVAC systems and electrical systems as well as the need for possible specific surveys.
- Repair summaries concerning the needs for repairs over the 10-year period (e.g. 2016- 2025)
- Specified repair needs and condition risks with cost estimations either yearly (e.g. 2016-2025) or divided according to customer's needs, for example:
- Repairs needed immediately (e.g. 2016)
- Repairs needed in the 1-5 years' time span (e.g. 2017-2020)
- Repairs needed in the long term (e.g. 2021-2025)

In normal TDD project, the project manager then puts the reports together for the full report, proceeding for the quality checks and for sending the completed report to the customer. In the new service, after the reports are written they continue after the quality checks to the calculation phase of the new energy service.

5.4 Phase 4, energy calculations for the specific tasks in the LTP

Now the process goes to the new energy service. Here the author of the energy efficiency potential calculations takes the LTP into inspection and takes the most potential energy efficiency improvements or deteriorations into further calculations. After choosing the tasks which will be calculated with the calculation tool or separately, the first calculated thing is the actual energy consumption at the time and then comparison of that consumption to the new calculation where the old object is changed to a new one. In LTP, there is a rough estimate of the costs of the task, which is typically justified with old or new offers from the suppliers, estimated with *Kustannustieto* (2015/2016 edition) from Haahtela, or with the best available knowledge of the expert. With these prices the payback period of the investments is calculated and if the payback period is shorter than the 30 years or the technical lifetime, also an upgrade to a technically even better one is taken into consideration. This comparison is also, done if the customer wants it. After the calculation is done, the author makes a report of the results founded with focus on:

- Information about the building's energy efficiency potential
- Consequence of system upgrades to the energy consumption
- Evaluation of the buildings energy consumption for the next 10 years

5.5 Phase 5, a property specific written report including all ordered TDD services

In typical TDD report, the most significant findings, analysis and consultant's reviews are collected to the property specific technical due diligence report including executive summary and recommendations for further actions. In addition, each of studied issues will be summarized in separate due diligence Excel-file that will be delivered to the customer as an attachment. The summary will include the studied object, a description about how the issue is reviewed, the major findings and a reference to the DD report.

The reporting shall be carried out in two stages:

1. Draft Report

- The customer's comments regarding the content and quality of the report. In other words; any errors or misinterpretation in the reports shall be submitted to the consultant.

2. Final Report

- The consultant shall take into account possible errors or misinterpretation in the reports and deliver the final report.

In the new energy service, also the summary of the energy efficiency potential of the building is reported as a part of the TDD reporting. The new service summaries the effect of the implemented LTP task in energy consumption and saving or backfire potential of the new equipment's or improvements. In the TDD reporting the new service is planned to be added into the typical TDD reporting as an attachment.

6 Energy Calculation

The calculation tool used in this thesis and in the case studies is built and modified according to the rules given in the new Finnish building regulations under circulation of comments and completed by energy efficiency regulations which are given by the Finnish ministry of the environment in 2013. The tool is implemented with Microsoft Excel and Visual basic. The calculation tool takes into consideration the heat accumulation of the structures in at least one hour time steps. The calculation tool uses simple dynamic thermal simulation to analyse the thermal and energy behaviours of a building. For specific technical solutions for example pumps, the energy savings potential is calculated using running times and Specific Fan Power (SFP) number only. In Table 6, the needed starting values for the calculation tool are introduced. The calculation process is introduced more detailed in the coming paragraphs of this chapter.

Table 6. Starting values needed for the calculation tool

The needed starting values for the calculation tool		
Number of storeys[pcs.]		Temperature of supply air[⁰C]
Storey high[m]		The correlation between the air flows
Building Gross-area[m²]		The efficiency of the heat recovery
Ground temperature[ºC]		The minimum temperature of waste air
Wall and window areas to principal compass points[m²]		Set point of cooling[⁰C]
U-values of windows and structures[W/m²K]		Percentual amount of the cooled area[%]
District heating or electrical heating		SFP/COP number of the water cooling unit
Efficiency of the district heating distribution		Cooling of the supply air [kW]
Set point of the heating[⁰C]		Is the water heated with electricity or district heating
SFP-number of fans[kW/m³/s]		What is annual consupmtion of water[dm³/m²a]
designed air flow[dm³/m²]		The efficiency betweenthe heat distribution and heat supply
District heating or electrical heating of supply air		The external heat loads[W/m²]

The basic dynamic simulation were selected as a calculation tool of the thesis, because of the dynamic simulation are much more accurate and versatile than the monthly based methods, even though the dynamic simulation tools have a higher potential of errors due the large amount of initial data required in the calculations. (Pietiläinen et. al. 2007) Also the national building code of Finland part D3 requires dynamic simulation tool for buildings where cooling is applied, so the use of dynamic simulation tool is justified and needed if the new energy service is applied in apartment buildings with cooling applied.

(NBCF, D3, 2012) The accuracy of the dynamic simulation comes from the small time steps, which allows the calculations take the change in environmental conditions, for example temperature and intensity of the radiation of the sun into account. This means that the spaces and the technical systems of the model interact with each other and the energy balance of the model can be defined more accurate giving more detailed solutions, when for example, windows are changed in the model. This character gives the new energy service a possibility to compere different types of building materials more accurate but still being time efficient. The used dynamic simulation tool also provides hourly information of the temperature conditions inside the building, if the customers want to see how the building behaves in different outside situations.

6.1 General Description of the Calculation Method

The calculation tool uses a nodal point model to simulate the heat transfer and the heat accumulation of the structures. In Figure 15, is a simplified heat dynamic model of a brick wall, where the temperature $T_{\mathrm{u}} = f(t)$ and $T_{\mathrm{s}} = f(t)$ in both sides of the wall changes as a function of time.

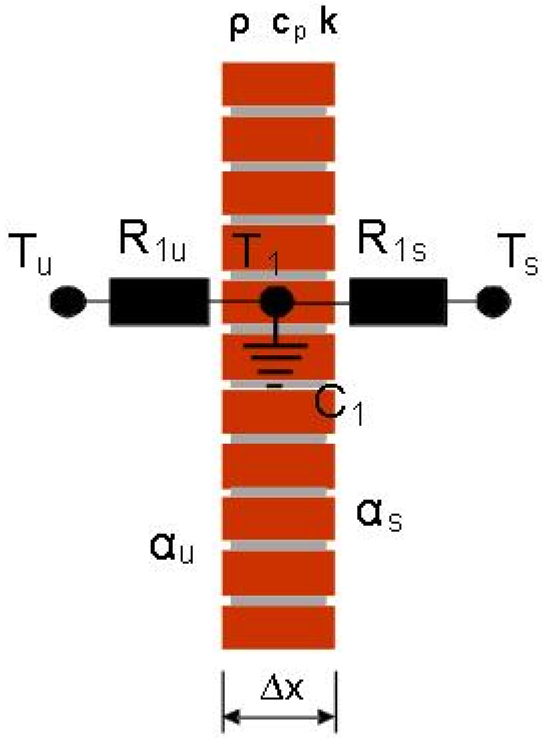

Figure 15. Heat dynamic model of a brick wall (Adopted from Sirén, 2015, p. 3)

Now we want to know the heat flow to the building from the warmer side. Let us assume that the heat transfer is unidimensional, meaning that the heat transfers only in the horizontal direction, not in the vertical. The heat nodal point T_1 [K] describes the temperature of the whole brick wall and it is connected with the heat capacity C_1 [kJ/kgK] of the whole brick wall. The thermal resistance from the nodal point of the wall to the nodal point of the outside temperature forms from the half of the thermal resistance of the wall and from the convective heat resistance of the outer surface of the wall as follows:

$$R_{1\mathrm{u}} = \frac{\frac{\Delta x}{2}}{kA} + \frac{1}{\alpha_u A} \tag{1}$$

Where, A [m²] is the area of the wall and k [W/Km] the average thermal conductivity of the wall material. In a corresponding way the thermal resistance of the wall $R_{1\mathrm{s}}$ [K/W] is calculated from the nodal point of the wall to the temperature point of the inside temperature. Heat capacity of the temperature point T_1 connected to the temperature point of the wall is:

$$C_1 = A\Delta x \rho c_{\mathrm{p}} \tag{2}$$

Where, ρ [kg/m³] is the density of the wall material and c_{p} [kJ/kgK] is the specific heat capacity of the wall material. Now, we can write a heat balance to the wall as follows:

$$C_1 \frac{dT_1}{dt} = G_{1\mathrm{u}}(T_{\mathrm{u}} - T_1) + G_{1\mathrm{s}}(T_{\mathrm{s}} - T_1) \tag{3}$$

Where, reciprocals of the resistance are marked as heat conductance $G_{1\mathrm{u}} = 1/R_{1\mathrm{u}}$ [W/K] and $G_{1\mathrm{s}} = 1/R_{1\mathrm{s}}$ [W/K]. The left side of the Equation 3, represents the thermal power that the mass of the brick wall accumulates or transfers and the right side represents the heat flows coming and going from the wall. At every period of time, the value of the heat flows must be the same as the accumulated thermal power.

The Differential Equation 3, can be solved easily with analytical methods, but in more complex cases, like the ones in this thesis, the analytical method is no longer valid and we need to use a simple numerical difference method. This is why we discrete the Equation 3, as follows:

$$\frac{dT_1}{dt} = \frac{T_1 - T_{1-1}}{\Delta T} \tag{4}$$

Where, T_1 [K] is the temperature of the wall at the present and T_{1-1} [K] is the temperature at the previous calculation period. The time steps between the calculations are marked with Δt [h]. Solving the unknown temperature from Equation 4, we get:

$$T_1 = T_{1-1} + \frac{dT}{dt}\Delta T \tag{5}$$

Where, the derivative from the Equation 3, can be chosen to represent different moments of time, giving us different variations of the calculating method. Substituting the current time to the corresponding time in Equation 5, we get:

$$T_1 = T_{1-1} + \frac{\Delta t}{C_1}\left[G_{1\mathrm{u}}(T_{\mathrm{u}} - T_1) + G_{1\mathrm{s}}(T_{\mathrm{s}} - T_1)\right] \tag{6}$$

Where, the temperature of the previous time T_{1-1} [K] is known and the temperature of the current time can be calculated as follows:

$$T_1 = \frac{T_{1-1} + \frac{\Delta t}{C_1} G_{1\mathrm{u}} T_{\mathrm{u}} + \frac{\Delta t}{C_1} G_{1\mathrm{s}} T_{\mathrm{s}}}{1 + \frac{\Delta t}{C_1} G_{1\mathrm{u}} + \frac{\Delta t}{C_1} G_{1\mathrm{s}}} \tag{7}$$

This method to discrete the temperature over time is called the implicit method. The reason why the calculation tool used in this thesis uses the implicit method is the stability of the method. The answer acquired with the implicit method does not oscillate under any circumstances. (Sirén, 2015, p. 3-6)

6.2 Calculation Tool

The calculation method described in Chapter 6.1, can be implemented to use multiple nodal points. With multiple nodal points, the outcome of the calculation is more accurate and it gives us the chance to add more systems (points) to the calculation. In Figure 16, we can see the implemented nodal point model that the operated calculation tool uses.

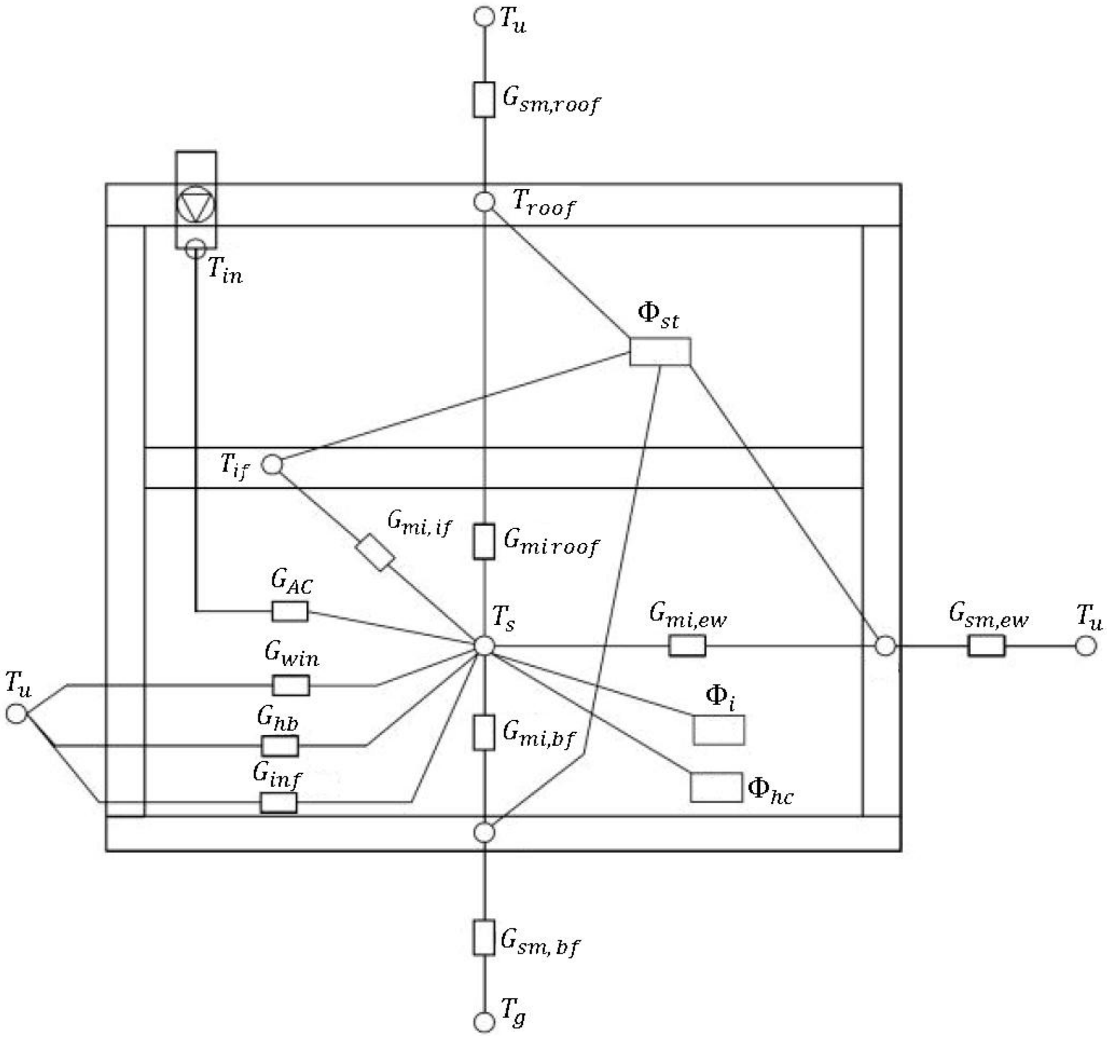

Figure 16. The implemented nodal point model in the calculation tool

Where, T letters means the nodal points that have temperature [K] and heat capacity [kJ/kgK or J/K], except the nodal point of the incoming air, which does not have capacity. G_{sm} [W/K] is the conductance between the structure and the outside air, G_{mi} [W/K] is the conductance between the structure and the inside air, G_{AC} [W/K] is conductance of the air conditioning, G_{win} is conductance of the windows, G_{inf} [W/K] is the heat capacity flow of the infiltration air flow, G_{hb} [W/K] is the conductance of the thermal bridges. The lower indexes means: s, is inside air, u, is outside air, g, is ground, in, is incoming air, ew, is external wall, bf, is base floor, if, is intermediate floor, $\emptyset_{\text{hc}}$ [W], is heating and cooling power, $\emptyset_{\text{i}}$ [W], is convective heat powers effective to the nodal point of the inside air and $\emptyset_{\mathrm{m}}$ [W] is the radiation heat effective to the structure nodal points.

The answers calculated with the tool, are approximates and the end user should not try to calculate, for example the E-value or the heat balances during summer time with the calculation tool. The absolute values given by the calculation tool should be inspected with criticism. On the other hand the calculation tool is good when the user comperes values inside the calculation tool and compere them to each other or as a proportional of the results. This character gives us the possibility to quickly and effectively calculate and compere the changes in the energy consumption, if LTP tasks are a bigger renovation, for example, to the air condition devices, windows or structural elements.

6.2.1 Heat Balances

The nodal points are connected to each other with the routes of the heat flow representing the heat conductance or the heat capacity of the mass flows (for example, air conditioning). The nodal point model in Figure 16, is based on the balance equations. Temperatures and the needed heating and cooling powers are calculated with these balance equations:

Heat balance of the nodal points of the enclosing structures us, ap and yp as follows:

$$G_{\mathrm{sm,n}}\left(T_{\mathrm{u}} - T_{\mathrm{m,n}}\right) + G_{\mathrm{mi,n}}\left(T_{\mathrm{s}} - T_{\mathrm{m,n}}\right) + \Phi_{\mathrm{m,n}} = C_{\mathrm{m,n}} \frac{dT_{\mathrm{m,n}}}{dt} \tag{8}$$

Where,

$G_{\mathrm{sm,n}}$	is the conductance of the enclosing structure and inside air [W/K]
$G_{\mathrm{mi,n}}$	is the conductance of the enclosing structure and outside air [W/K]
$T_{\mathrm{m,n}}$	is the temperature of the structure nodal point n [K]
Φ_{m}	is the emittance effecting to the structure nodal point [W]
$C_{\mathrm{m,n}}$	is the heat capacity of the structure nodal point n [J/K]
d/dt	is the time differential [-]

This differential equation can be modified to normal algebraic equation by using implicit discrete, meaning that the right side of the Equation 8, is replaced by the term:

$$C_{m,n} \frac{T_{m,n} - T_{m,n-1}}{\Delta T}$$

Where,

$T_{\mathrm{m,n-1}}$	is the temperature of the previous time step at the nodal point n [K]
Δt	is the time step used [h]

Now, we can solve the $T_{\mathrm{m,n}}$ [K]. The temperature of the nodal points of the enclosing structures is calculated with equation:

$$T_{\mathrm{m,n}} = \frac{\frac{C_{\mathrm{m,n}} T_{\mathrm{m,n-1}}}{\Delta T} + G_{\mathrm{sm,n}} T_{\mathrm{u}} + G_{\mathrm{mi,n}} T_{\mathrm{s}} + \Phi_{\mathrm{m,n}}}{\frac{C_{\mathrm{m,n}}}{\Delta T} + G_{\mathrm{sm,n}} + G_{\mathrm{mi.n}}} \tag{9}$$

The nodal point of the intermediate floor differs from the other nodal points because it is not connected with outside air. To calculate the temperature of the intermediate floor, the applied principle is the same used with enclosing structures. The equation comes to the form:

$$T_{\mathrm{if}} = \frac{\frac{C_{\mathrm{if}} T_{\mathrm{if-1}}}{\Delta T} + G_{\mathrm{mi.if}} T_{\mathrm{s}} + \Phi_{\mathrm{m,if}}}{\frac{C_{\mathrm{if}}}{\Delta T} + G_{\mathrm{mi,if}}} \tag{10}$$

The nodal point of the air is calculated as follows:

$$\sum \left(G_{mi,n} \left(T_{m,n} - T_s \right) \right) + \mathrm{G}(T_t - T_s) + \left(G_{win} + G_{inf} + \mathrm{G} \right)(T_u - T_s) + \Phi_s + \Phi_{hc} = C_s \frac{dT_i}{dt} \tag{11}$$

Where,

$\sum \left(G_{\mathrm{mi,n}} \left(T_{\mathrm{m,n}} - T_{\mathrm{s}} \right) \right)$ is the sum of all the structural nodal point terms $G_{\mathrm{mi}}(T_{\mathrm{m}} - T_{\mathrm{s}})$ connected to the nodal point of the air. C_{s} [J/K] is the heat capacity of the air nodal point.

The implicit discrete is implemented for Equation 11, as in Equation 8. After this we can solve the inside temperature as follows:

$$T_{\mathrm{s}} = \frac{\frac{C_{\mathrm{s}} T_{\mathrm{s-1}}}{\Delta T} + \sum(G_{\mathrm{mi,n}} T_{\mathrm{m,n}}) + T_{\mathrm{u}}(G_{\mathrm{inf}} + G_{\mathrm{win}} + G_{\mathrm{hb}}) + T_{\mathrm{t}} G_{\mathrm{AC}} + \Phi_{\mathrm{i}} + \Phi_{\mathrm{hc}}}{\frac{C_{\mathrm{s}}}{\Delta T} + \sum G_{\mathrm{mi,n}} + G_{\mathrm{inf}} + G_{\mathrm{win}} + G_{\mathrm{AC}} + G_{\mathrm{hb}}} \tag{12}$$

From Equation 11, we can also calculate the heating or cooling power in specific time as follows:

$$\Phi_{\mathrm{hc}} = \left(\left(\sum G_{\mathrm{mi,n}} \right) + G_{\mathrm{AC}} + G_{\mathrm{win}} + G_{\mathrm{inf}} + G_{\mathrm{hb}} \right) T_{\mathrm{s,set}} - \sum \left(G_{\mathrm{mi,n}} T_{\mathrm{m,n}} \right) - G_{\mathrm{AC}} T_{\mathrm{t}} - (G_{\mathrm{inf}} + G_{\mathrm{win}} + H_{\mathrm{hb}}) T_{\mathrm{u}} - \Phi_{\mathrm{i}} + \frac{C_{\mathrm{s}}(T_{\mathrm{s}} - T_{\mathrm{s-1}})}{\Delta T} \tag{13}$$

Where,

$T_{\mathrm{s,set}}$ is the set point of the inside air [K]

In the Excel, the actual calculation procedure starts by calculating all the structural nodal point temperatures with Equations 9 and 10. For the first time step, we need to guess the first temperature of the structural nodal point $T_{\mathrm{m,n-1}}$ and of the inside air. For structural nodal point, the first guess is between the outside and the inside temperature. The starting value of the inside air is in this thesis 21 °C. After we know all the temperatures, we can calculate the so called floating temperature with Equation 12. The floating temperature means the inside temperature without heating or cooling power, so the term $\emptyset_{\mathrm{hc}}$ is zero. With the achieved floating temperature, the needed cooling or heating power can be calculated with the knowledge that the power needed to heat or cooldown the supply air to achieve the temperature set point is the actual cooling or heating power. This means that if the floating temperature is above the set point of cooling temperature cooling power is needed and if it is under the set point of the heating temperature heating power is needed. The needed heating or cooling power is the power added to supply air to achieve the set point. If the floating temperature sets between the cooling and heating set points the needed cooling and heating power is approximated to zero. The $\emptyset_{\mathrm{hc}}$ can be calculated directly with Equation 13. With this power, the real temperature of the inside air nodal point can be calculated with Equation 12. Now, as an answer the temperature of the set point of the inside air or the floating temperature is obtained, if the $\emptyset_{\mathrm{hc}} = 0$. Now the tool has calculated one round and the second can be done the same way as described above. The starting values for the temperature of the structural nodal points are obtained from the previous calculation round and the inside air temperature.

6.2.2 Conductance

6.2.2.1 Conductance of the Enclosing Structures

The heat flow between inside and outside air goes through the enclosing structures with two conductance's, G_{mi} [W/K] and G_{sm} [W/K]. The sum of these conductance's forms the U-value for the enclosing structures. Conductance's are formed as follows: Firstly the conductance between inside air and structure, H_{mi}, is calculated with equation:

$$G_{\mathrm{mi}} = A_{\mathrm{m}} \alpha_{\mathrm{mi}} \tag{14}$$

Where,

A_{m} is the area connected to the inside air [m²]

α_{mi} is the heat transfer factor between inside air and the nodal point [-]

After G_{mi} is determined, we can calculate G_{sm} with exigency that the total conductance $G_{\mathrm{m,tot}}$ [W/K] is:

$$G_{\mathrm{m,tot}} = U_{\mathrm{m,tot}} A_{\mathrm{m}} \tag{15}$$

Where,

$U_{\mathrm{m,tot}}$ is the total U-value for the structure in question [W/m²K]

Now the conductance's are in series. Taking the series into consideration, the conductance of G_{sm} [W/K] needs to be calculated as follows:

$$G_{\mathrm{sm}} = \frac{1}{\frac{1}{G_{\mathrm{m,tot}}} - \frac{1}{G_{\mathrm{mi}}}} \tag{16}$$

When the conductance is calculated this way, the U-value of the structure is constant.

Conductance between the intermediate floor and the inside air is calculated with Equation 14.

6.2.2.2 Conductance of the Windows

The heat conductance of the windows G_{win} [W/K], is calculated with Equation 15, because of the heat flow which is connected directly to the inside air.

6.2.2.3 Conductance of the Infiltration Air

Conductance of the infiltration air G_{inf} [W/K], is calculated as follows:

$$G_{\mathrm{inf}} = q_{\mathrm{inf}} c_{pi} \rho_{\mathrm{i}} \tag{17}$$

Where,

q_{inf}	is the flow of the infiltration air [m³/s]
c_{pi}	is the specific heat capacity of the air [kJ/kgK]
ρ_{i}	is the density of the air [kg/m³]

6.2.2.4 Conductance of the Supply Air

The conductance of the supply air is defined with Equation 17, the same way as the conductance of the infiltration air. In the equation, the supply air flow is used in the place of the term q_{inf} when calculating the conductance of the supply air. This is why the conductance of the supply air can have variation if the supply air flow is not constant.

6.2.2.5 Conductance of the Thermal Bridges

The conductance of the thermal bridges consists of five different joints and their extra conductance. The five joints are:

- The joint between the corner of the two external walls
- The joint between the external wall and the roof
- The joint between the external wall and the base floor
- The joint between the external wall and the intermediate floor
- The joint between the external wall and the windows

The calculation tool approximates the lengths of the different types of joints with equations the following:

$$l_{\mathrm{ew/ew}} = 4 n_{\mathrm{floor}} H_{\mathrm{floor}} \tag{18}$$

Where,

$l_{\mathrm{ew/ew}}$	is the total length of the joints between the corners of the two external walls (vertically 4 pcs.) [m]
n_{floor}	is the quantity of the floors [-]
H_{floor}	is the height of the floor [m]

$$l_{\mathrm{ew/roof}} = 4\sqrt{A_{\mathrm{roof}}} \tag{19}$$

Where,

A_{roof}	is the area of the roof [m²]
$l_{\mathrm{ew/roof}}$	is the length of the joints between the external wall and the roof (4 sides) [m]

$$l_{\mathrm{ew/roof}} = 4\sqrt{A_{\mathrm{roof}}} \tag{20}$$

Where,

A_{roof}	is the area of the base floor [m²]
$l_{\mathrm{ew/roof}}$	is the length of the joints between the external wall and the base floor (4 sides) [m]

$$l_{\mathrm{ew/if}} = 2\left((n_{\mathrm{floor}} - 1)4\sqrt{A_{\mathrm{bf}}}\right) \tag{21}$$

Where,

$l_{\mathrm{ew/if}}$	is the length of the joins between the external walls and the intermediate floor (4 sides) [m]
2	is a factor that takes into account that every intermediate floor generates 2 extra conductance's that are line shaped

$$l_{\mathrm{ew/win}} = \left(\frac{A_{\mathrm{win,tot}}}{(l_{\mathrm{win,norm}})^2}\right) 4 l_{\mathrm{win,norm}} \tag{22}$$

Where,

$l_{\mathrm{win,norm}}$	is the length of the typical window [m]
$l_{\mathrm{ew/win}}$	is the length of the joints between the external wall and the windows [m]
$A_{\mathrm{win,tot}}$	is the total window area [m²]

The size of the typical windows affects to the length of the joints between the external walls and the windows. If the windows sizes are big there is smaller amount of windows in the building and the joint length is smaller and vice versa.

6.2.3 Internal Thermal Loads

The heat gains of the nodal point model can be divided into two different categories: convective loads and radiant heat loads. These loads effect directly to the nodal point of the inside air and they are marked with symbol $\emptyset_{\mathrm{i}}$ [W]. These thermal loads include the convective part of the thermal loads from lighting, occupants and electrical equipment's. The convective part means the part of the thermal load which is directly transferred to the inside air trough conduction. The convective part can be defined for the foregoing three groups of the heat loads. If we do not have a specific knowledge of the shares of the heat loads the tool uses for lighting a share of 0.3, people 0.7 and electrical equipment 1.0. Similarly, the part of the radiation amount for the structural nodal points $\emptyset_{\mathrm{m}}$ [-] is calculated as 1 minus the convective part. For example for the lighting: $\emptyset_{\mathrm{m}} = 1 - 0.3 = 0.7$. The parts of the inside thermal loads are divided between the structural nodal points directly according to the ratio of the structure areas.

Initial values for the inside heating loads are specified in $\frac{W}{m^2}$, which map the maximum heat power of the load. These loads are then multiplied with the part of the load (0…1). The loads can be determined for different demands with time scheduling that can variate every single day or hour. This means that the load schedule of every heat load can be determined for every hour in question.

6.2.4 Thermal Load from the Sun

The thermal load from the sun and the radiation power coming through the windows is divided between the structural nodal points. This means that the thermal power and radiation power from the sun is included in the term $\emptyset_{\mathrm{m}}$. The radiation power from the sun is also divided between the different structural nodes directly in ratio of the areas. The divided direct radiation power of the sun is calculated with equation:

$$\Phi_{\mathrm{sun}} = \phi_{\mathrm{sun}} A_{win} g(1 - (1 - cos\theta)^3)\tau F_f \tag{23}$$

Where,

Φ_{sun}	is the direct radiation power of the sun through the window [W]
ϕ_{sun}	is the intensity of the radiation to the external surface of the window [W/m²]
g	is the g- value of the window [-]
θ	is the angle of the direct radiation to the window [°]
τ	is the penetration factor of the sunshade [-]
F_f	is the frame factor of the window [-]

The radiation of the sun generates a direct solar load to the external surface of the structures of the building. This thermal load is taken into account with the so called sun temperature T_{sun} [K]. This temperature is a theoretical temperature of the outside air at the surface of the enclosing structures, which rises when the sun radiation heats the wall. The sun temperature is calculated with equation:

$$T_{\text{sun}} = T_{\text{u}} + \frac{\alpha_j \phi_{\text{sun,tot}}}{h_{\text{j}}} \tag{24}$$

Where,

α_{j}	is the absorption factor of the external surface of the wall for the radiation of the sun [-]
$\phi_{\text{sun,tot}}$	is the specific radiant power for the wall [W/m²]
h_{j}	is the convective heat transfer coefficient for the external surface of the wall [W/m²K]

Equation 24, is used to compensate the outside temperatures in Equation 9. The sun temperature is also used as a temperature outside of the windows and as an outside temperature affecting to the thermal bridges. This changes the Equation 12 to form:

$$T_{\text{s}} = \frac{\frac{C_{\text{S}} T_{\text{S}-1}}{\Delta T} + \sum\left(G_{\text{mi,n}} T_{\text{m,n}}\right) + T_{\text{sun}}\left(G_{\text{hb}} + G_{\text{win}}\right) + T_{\text{u}} G_{\text{inf}} + T_{\text{t}} G_{\text{AC}} + \Phi_{\text{i}} + \Phi_{\text{hc}}}{\frac{C_{\text{S}}}{\Delta T} + \sum G_{\text{mi.n}} + G_{\text{inf}} + G_{\text{win}} + G_{\text{AC}} + G_{\text{hb}}} \tag{25}$$

6.2.5 Technical Systems

The building's net need of energy is calculated with the nodal point model presented below. This calculation does not take into account the losses of the used technical systems such as efficiency etc. These things are taken into consideration in the calculations of the technical systems, where the purchased energy is calculated using the net energy need. In this chapter all the calculation's for the technical systems integrated into the calculation tool are introduced.

6.2.5.1 Air Conditioning

The supply air flow in the calculation tool is determined as follows:

$$q_{in} = \frac{q_{\text{m}} A n_{\text{AC}}}{1000}$$

(26)

Where,

q_{in}	is the supply air flow into the building [m³/s]
q_{m}	is the planned supply air flow into the building [m³/m²]

A	is the gross area of the building [m²]
n_{AC}	is the hourly adjustment factor for the air flows [-]

The yearly electricity usage of the supply fans is calculated using the specific fan power (SFP) number and the amount of supply air. The SFP number is divided by 2, because it is assumed that the SFP number is calculated evenly with supply and exhaust fans. In cases where we do not have supply fans, the SFP number is allocated totally to the exhaust fan.

$$\phi_{\mathrm{AC,sup}} = \frac{\frac{SFP}{2} V_{\mathrm{sup}}}{3600} \tag{27}$$

Where,

SFP	is the specific fan power [kW/(m^3/s)]
V_{sup}	is the yearly supply air flow of the building [m³]
$\phi_{\mathrm{AC,sup}}$	is the yearly electricity consumption of the supply fan [kW]

The yearly electricity for consumption by the exhaust air fans is calculated the same way as the supply fans.

$$\phi_{\mathrm{AC,exh}} = \frac{\frac{SFP}{2} V_{\mathrm{exh}}}{3600} \tag{28}$$

Where,

$\phi_{\mathrm{AC,exh}}$	is the yearly electricity consumption of the exhaust fan [kW]
V_{exh}	is the yearly exhaust air flow of the building [m³]

The V_{exh} is calculated with the knowledge of the yearly supply air flow of the building and the proportion of supply and exhaust air, as follows:

$$V_{\mathrm{exh}} = \frac{V_{\mathrm{sup}}}{R} \tag{29}$$

Where,

R	is the proportion of the supply air to exhaust air [-]

The temperature of the supply air affects to the heating or cooling need of the supply air and this why also to the energy consumption of the air conditioning. The temperature set point of the supply air depends on whether does the inspected building has a cooling coil or not, and what is the adjustment style of the cooling. In the calculation tool, two different options can be chosen: constant temperature or control curve.

6.2.5.2 Heat Recovery

The efficiency of the heat recovery is calculated hourly and it is calculated by applying the annual efficiency of the heat recovery. This means that the calculation tool takes into account the proportion of the supply to exhaust air R, the effect of the anti-freezing inhibition to the extract air temperature and the temperature restriction on summer time. The starting point of the momentary efficiency of the heat recovery is the temperature efficiency with the assumption that the supply and exhaust air flows are in balance. If the flows are unbalanced it affects the temperature efficiency and the efficiency must be calculated as follows:

$$\eta_{\mathrm{t}} = \frac{2\eta_{\mathrm{temp}}}{1+R} \tag{30}$$

Where,

η_{t} is the temperature efficiency of the heat recovery [-]

η_{temp} is the temperature efficiency when the air flows are in balance [-]

Next, the temperature of the air before the heating or cooling coil $T_{\mathrm{LTO,floating}}$ [K] is calculated without taking any restrictions into account.

$$T_{\mathrm{HR,floating}} = \eta_{\mathrm{t}}\left(T_{\mathrm{p}} - T_{\mathrm{u}}\right) + T_{\mathrm{u}} \tag{31}$$

Where,

T_{p} is the temperature of the exhaust air [K]

T_{u} is the temperature of the outside air [K]

During the winter season, there is a risk that the heat recovery can freeze if the temperature of the extract air is not restricted. This why the efficiency of the heat recovery changes, if the temperature of the extract air is under the set point minimum. If this happens, the efficiency of the heat recovery is calculated as follows:

$$\eta_{HR} = \frac{T_s - T_{ice}}{T_s - T_u} \tag{32}$$

Where,

η_{HR} is the efficiency of the heat recovery [-]

T_{s} is the temperature of the inside air, which is the same as the temperature of the exhaust air [K]

T_{ice} is the minimum temperature (set point) of the extract air [K]

When the temperature of the extract air is above the minimum set point, the efficiency of the heat recovery is $\eta_{\mathrm{HR}} = \eta_{\mathrm{t}}$

During the summer season, the outside temperature rises, which means that also in the summer time the supply air temperature needs to be restricted to ensure that the temperature of the supply air does not raise too much because of the heat recovery. For example, this kind of situation can happen when the set point of the supply air is 18°C, outside temperature is 17°C and the exhaust temperature is 25°C. In this case, if the heat recovery works with full efficiency, the supply air will be heated up above the set point and the piece of real estate will be supplied with too hot air. This kind of situation is controlled in the calculations as follows:

If the argument

$$T_{\mathrm{HR,floating}} > T_{\mathrm{sup}} \tag{33}$$

is true, then:

$$\eta_{\mathrm{HR}} = \frac{T_{\mathrm{sup}} - T_{\mathrm{u}}}{T_{\mathrm{s}} - T_{\mathrm{u}}} \tag{34}$$

Where,
T_{sup} is the set point temperature of the supply air [K]

The situation mentioned above means that, if the supply air temperature rises too high after the heat recovery, the efficiency of the heat recovery is decreased by replacing the T_{LTO} with the supply air set point T_{sup}. This how, the efficiency of the heat recovery is decreased to the point that the supply air temperature T_{sup} is achieved. When the temperature of the outside air rises too high and a heat recovery restriction is not enough and we need to shut down the heat recovery, because the efficiency cannot have negative values. This overrules the situation described before. The shutdown situation happens, if the following rule applies:

$$\eta_{\mathrm{HR}} = \frac{T_{\mathrm{sup}} - T_{\mathrm{u}}}{T_{\mathrm{s}} - T_{\mathrm{u}}} < 0 \tag{35}$$

Then,
$\eta_{\mathrm{HR}} = 0$

6.2.5.3 The Power Need of the Cooling and Heating Coils

With the equations presented in the previous chapter, we can now calculate the efficiencies of the heat recovery for every situation. Now, the true temperature of the supply air after the heat recovery is calculated as follows:

$$T_{\mathrm{HR}} = \eta_{\mathrm{HR}}\left(T_{\mathrm{p}} - T_{\mathrm{u}}\right) + T_{\mathrm{u}} \tag{36}$$

With T_{HR} we can calculate the heat power recovered from the exhaust air as follows:

$$P_{\mathrm{HR}} = \rho_{\mathrm{i}} c_{\mathrm{pi}} q_{\mathrm{AC}} (T_{\mathrm{HR}} - T_{\mathrm{u}}) \tag{37}$$

Where,
P_{HR} is the heat power obtained with the heat recovery from the exhaust air [W]
q_{AC} is the air flow of the air conditioning system [m³/s]

The power produced by the heating coil is

$$P_{\mathrm{heating\ coil}} = P_{\mathrm{L,AC,Net}} - P_{\mathrm{HR}} \tag{38}$$

Where,
$P_{\mathrm{L,AC,Net}}$ is the heating power [W] needed to heat up the supply air or:

$$P_{\mathrm{AC,L}} = \rho_{\mathrm{i}} c_{\mathrm{pi}} q_{\mathrm{AC}} \Delta T_{\mathrm{i}} \tag{39}$$

Where,
ΔT_{i} is the difference between the outside and the set point temperature [K]

The power needed for cooling the supply air is calculated as follows:

$$\phi_{\mathrm{AC,j}} = \rho_{\mathrm{i}} c_{\mathrm{pi}} q_{\mathrm{AC}} \Delta T_{\mathrm{i}} \tau_{\mathrm{condensate}} \tag{40}$$

Where,
$\tau_{\text{condensate}}$ [-] is the factor taking into account the extra cooling power needed to compensate the heating power released by the phase change of the water condensing onto the surface of the cooling coil.

6.2.5.4 Heating System of the Water Supply

The heating system of the water supply differs from the heating system of the air conditioning and building. Firstly, it is assumed that the consumption of water is constant during the whole year. Secondly, the water supply has two different options it can use as the heating system, district heating or direct electricity heating. These two systems have specific rules in the calculation tool.

- District heating and direct electricity heating cannot be used at the same time
- If the system has both of the systems available, the calculation tool uses district heating
- The energy used to heat up the domestic hot water is done as follows: Firstly, we need to calculate the net need of the energy, $E_{\text{DHW,net}}$ [kWh], to heat up the domestic hot water with equation:

$$E_{\text{DHW,net}} = \frac{\rho_{\text{w}} c_{\text{pw}} V_{\text{w}} \Delta T}{3600} \tag{41}$$

Where,
ρ_{w} is the density of the water [kg/m³]
c_{pw} is the specific heat capacity of the water [kJ/kgK]
V_{w} is the yearly volume of the water consumed [m³]
ΔT is the temperature difference between the heated water and the supplied water [K]
Because the consumed water on a yearly basis is divided evently on all days, the heating energy is modified to the needed heating power with the equation:

$$\phi_{\text{DHW}} = \frac{E_{\text{DHW,net}}}{8760} \tag{42}$$

Heat losses of the recirculation of domestic hot water ring duct $\phi_{\text{DHW,loss}}$ [W/m²] are also taken into account in the calculations. The heat losses are automatically added to the energy consumption of the heating system and that is why they increase the energy consumption of heating up the domestic hot water. Because, in reality, some of the heat losses transfer into the spaces as a positive heat flow, the calculation tool can utilize this energy. $\lambda_{\text{LKV,uti}}$ is the percentage of the reduced need of heating which is utilized from the heat losses of the domestic hot water ring duct. This power is transferred as an event daily part of the heating power straight to the air nodal point. In another words, this power includes in the term Φ_{i} in Equations 12 and 13.

6.3 Energy Investments

The price development of the energy deviates from the typical inflation, because the price of the energy can change in a short time period. It is not smart to bind the energy price to the normal price development, but to analyze it as an independent factor. Escalation represents the deviation of energy price. Escalation is calculated with the equation:

$$r_{\mathrm{e}} = \frac{i - f_{\mathrm{e}}}{1 + f_{\mathrm{e}}} \tag{43}$$

Where,

i is the real interest rate [-]
r_{e} is the real interest rate taking the escalation into consideration [-]
f_{e} is the escalation [-]

Then the discounting factor is calculated as follows:

$$a''_{\mathrm{n}} = \frac{1 - (1 + r_{\mathrm{e}})^{-n}}{r_{\mathrm{e}}} \tag{44}$$

Where,

a''_{n} is the discounting factor taking the escalation into consideration [-]
n is the investment time in years [a]

Now, the net present value of the investment is calculated, when assuming that the residual values of the investments are zero and the returns and expenses are constant, with equation as follows:

$$P = a''_{\mathrm{n}} A - I_0 \tag{45}$$

Where,

P is the net present value of the investment [€]
I_0 is the investment cost [€]
A is the yearly achieved monetary energy savings of the investment [€/a]

To get the payback period N[a] of the investment, we need to divide the investment cost I_0 with the achieved monetary energy savings of the investment A, which is multiplied with the discounting factor a''_{n}, taking the escalation into consideration. As an equation it is:

$$N = \frac{I_0}{A a''_{\mathrm{n}}} \tag{46}$$

If we want directly achieve the payback period (PBP), we can calculate it as follows:

$$N = \frac{-ln\left(\frac{1}{f_{\mathrm{e}}} - \frac{P}{A}\right) - ln(f_{\mathrm{e}})}{ln(1 + f_{\mathrm{e}})} \tag{47}$$

(Sirén, 2015), (Isaksson, 2014, p. 13)

In the investment calculations, this thesis uses the technical lifetimes of the systems or equipment's in question, or the maximum of 30 year period which is given by the Finnish Ministry of the Environment for apartment houses as an investment period. The typical lifetimes for technical systems and equipment are taken from the Finnish property management card 90-00403. As an escalation the thesis uses 2 % and 4 %.

7 Field Study

In this chapter of the thesis, the concept of the new energy service is tested in two different case studies. The first case is a group of four apartment buildings located in the city of Espoo and the second one is an apartment building located in the city of Helsinki. In both of the cases the expert team visiting the buildings was the same: Pasi Ruuska as an expert of the structural systems, Marko Salmela as an expert of the electrical systems and Jari Isaksson as an expert of the HVAC-systems. In both cases, the site visits were done accompanied by a person responsible for the maintenance of the building. The visits were done in spring 2016 and the thesis does not take any stand on the condition of the case buildings after the site visits.

Two different case buildings were given from different decades, for the case studies of the thesis. This was done to achieve variety in LTP action plans and main systems of the buildings. This how it is more efficient to prove that the calculation tool is good for its purpose and is the new service possible to carry out like planned in the thesis.

In the next chapters, the field study is carried out in both of the cases as introduced in Chapter 5. In both of the cases, the first chapter introduces the basic data of the studied building, meaning that the thesis represents the main systems of the building in all three technical areas. Then in the following chapter, the work done back in the office after the site survey is presented in a form of an LTP proposal of the building. At this point the selected systems for the new energy service and further calculations are highlighted from the LTP. Thirdly, the calculations of the selected tasks are introduced and their influence on the energy consumption of the building is shown. Lastly, the affects and payback periods of the upgraded investments are studied and introduced.

The calculations in chapters 7.3 and 7.6 of the thesis are done with the calculation tool introduced in chapter 6 of the thesis, if there is nothing else said about the calculation method. The baseline of the energy consumption of the case buildings are calculated with the tool using the values reported, or achieved during the site visit. The LTP tasks chosen to the calculation phase of the new energy service are then added to the calculation tool to replace the old system. After the improvement the total energy consumption of the building is calculated again with the calculation tool and the potential energy saving or rebound is reported.

7.1 Basic Data Building 1

The real estate of the first case study consist of four different buildings from the year 1989, which divide a heat distribution center and a water main. The buildings are identified with numbers from 1 to 4. Buildings 1, 2 and 3 are identical in the height and building materials, but their orientation differs from each other. The fourth building has two extra storeys and different orientation. Otherwise the building 4 is build the same way as the other three buildings. The orientation of the target buildings are presented in Figure 17.

Figure 17. Town plan and orientation of the buildings in Case Study 1

All of the buildings have agency premises on the ground floor, but they are originally designed as they would be normal apartments, excluding the premises in the south east corner of Building 2, which is a restaurant and excluded from the case study. This is made because of all of the technical instruments are owned by the tenant and as a due diligence study they are not in scope of the TDD and the thesis.

According to the given initial data, there have been no bigger renovations in the real estate. The real estate has two air raid shelters and every building has their own sauna premises, which are in common use. The heat distribution center and water main are located in building number 2, and the electricity main distribution board is in building number 1. There are 86 apartments in the real estate, divided approximately even in the buildings. According to documents provided by the owner of the real estate, the gross area of the real estate is 7 717$m^2$and the heated volume is 22 990m^3. The area and volume information was not verified during the research.

The basic data of the property and the main systems and structures of the studied property are presented in Table 7.

Table 7. The basic data of the property

Basic data of the property			
Property type	Apartment building		
Square area	7 717	m^2	Gross area
Building volume	22 990	rm^3	
Year of construction	1989		
Enlargement years	-		
Renovation year	-		
Aboveground storeys	Building 1, 2 and 4 has four floors and building 3 has six floors		
Underground storeys	None		
Structures			
Foundations	Ground supported		
Building frame	Reinforced concrete		
External walls	Prefabricated panels		
Facade material	Brick-tile and white concrete		
Window type	Triple-glazed windows with triple-wooden frames		
Roof shape	Broken ridge roof		
Roofing material	Sheet metal roofing		
Traffic and parking areas	Minor areas, asphalt surface		
External constructions	Trash shelter		
Mechanical and automation systems			
Heating plant	District heating		
Heat dissipation	Room heaters, central water-heating, halls have circulated air heaters		
Water supply	Municipal water supply and sewer system		
Domestic water pipes	Copper pipes		
Sewage pipes	Cast iron pipes, band clamps		
Pumping stations	None		
Ventilation system	Mechanical exhaust air		
Cooling plant	None		
Cooling system	Small split-units in singular rooms		
Fire sprinkler system	None		
Building automation system	Separate adjusters and clock timing		
Electrical systems and transportation equipment			
Electric supply	Low voltage		
Distribution of electricity	4/5-conduit system (TN-C-S)		
Reserve power unit	None		
Kitchen devices	Small kitchens (kitchenettes) 89 pieces		
Fire alarm system	Non-indexed fire alarm system		
Antenna system	Own antenna system		
Burglar detection system	None		
Video surveillance system	None		
Access control system	None		
Lifts	5 pieces		

The data presented above describes the main systems and structures of the studied property, if any further information is not given.

7.2 Field Surveying of Case 1 and Long Term Renovation Plan

The field survey took place on 18th of March 2016. In the field survey, the condition of the real estate was studied by visual inspections and non-destructive procedures. Therefore any hidden defects linked with structural systems or technical systems cannot be uncovered in this type of study. The LTP is planned for 13 years perspective for years 2016-2028, because of the client's conation. All the buildings were inspected on the same day and the team made random inspections to ten different apartments during the study. Also almost all of the agency premises were inspected during the site visit.

7.2.1 Key Findings During The Site Visit

The structures of the building are mainly in acceptable condition. The estimated repair actions are mainly affects of ending technical lifetimes and local damages in structures. In the review period, the most significant separate structural repair need is the renewal of windows, balconies, roof covering and sanitary cabins. There were no structural drawings available in the initial data and those were not found during the site visit, so it is assumed that the foundation of the buildings is made on natural foundation bed. The walls and footings of the buildings are made from reinforced concrete. The windows originate from 1989 and they are in need of maintenance. The windows do not fulfill today's criteria of the energy efficiency and the renewal of the windows is recommended. The balconies and external doors are also at the end of their technical lifetime and recommended to be changed. According to the initial data and a condition assessment made in 2009, the renewal of the roof covering should be done at the beginning of the review period to avoid moisture problems and water leakage from the roof covering.

The HVACA- technologies of the buildings are mainly from the building year 1989, but the heat distribution center was renovated 2010 and it is in good condition. In the review period the most significant separate HVACA repair need is the renewal of the ventilation system and recirculation fans in the entrance of tambours. The heating network was adjusted at the same time when the heat distribution center was renovated. All of the four buildings use mechanical exhaust air as ventilation system. The fans are original from the building year and at the end of their technical lifetime during the first half of the review period. The recirculation fans come to the end of their technical lifecycle in the last half of the review period and are recommended to be changed. Building 1 has also one cooling unit serving small sale room, which is at the end of its technical lifetime and should be replaced at the beginning of the review period. The plumbing fixtures are in acceptable condition and they do not need to be changed or renovated for technical reasons during the review period.

The real estate's electrical systems are mainly from 1989 and in poor or acceptable condition. In the review period there are estimated big overhauls of the electrical systems mainly because of the end of the technical lifetimes. The most expensive repairs from an electrical point of view come from the renewal of the switchboards and maintenance of the lifts. The switchboards are mainly 4/5 conduit system's without fault mode current guards. The lighting in stair enclosures are renovated to light-emitting diode (LED) lamps, but the apartments, business and sauna premises still have the old lighting devices which are incandescent lighting. These old lamps come to the end of their technical lifecycle in the middle and at the end of the review period. The lamps are recommended to be changed to LED lamps. There is an electronical floor heating in the sanitary cabins of the apartments. The floor heating is renovated in the apartments where the sanitary cabins are renovated. The rests of the floor heating devices are from the building year 1989.

7.2.2 Long Term Renovation Plan for Case 1

After the site visit, the three experts made an LTP proposal for the real estate for the next 13 years. The proposal is justified by the condition of the structures and technical systems analysed during the site visit and their technical lifetimes. The LTP proposals also propose further investigations for example to the water and sewage networks, because there is a good reason to doubt that the network could have pinholing or there have been pinholes and tiny leakages in the network. These condition studies can also be proposed to the structural elements like front elevation or roof.

After the three experts have made their LTP proposals of the specific technical areas, they combine them into one report and compere the suggestions. For example, if the structural expert proposes a renewal of sanitary cabins in 2019 and the electrical experts is suggesting a full renewal of the lighting system in 2021, the two experts talk with each other and plan the task for the same year to avoid costly overlapping of LTP tasks and to gain advantages in the schedule and costs of the contract. Another example is in the ventilation system. If the air handling units are going to be changed in the near future, there is no reason for inside cleaning of the air ducts and adjustment of the air flows before the air handling units are changed.

The LTP plan for the first case study real estate is presented in Table 8. In the table, all the three technical elements are divided into their own tasks and the LTP tasks moving on to the calculation phase of the new energy service are colored pink. These tasks for the calculation phase are chosen because of the author of the thesis thinks that they the biggest effect on the buildings energy consumption.

In Table 8, the costs presented are mainly from the book Haahtela, Talonrakennus kustannustieto, 2015 edition. The costs coming to the energy calculations are revised to achieve more accurate cost is to for example for air condition devices, but if there is no knowledge of the prices, the costs are calculated with Haahtela and used in the calculations as such.

Table 8. The LTP plan for the case study real estate number one

T-90	Structure / System	Repair	Costs 1000 € (VAT 0%) Total	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
1. STRUCTURAL ELEMENTS																
D5	Pipelines on plot	tightness test of the pit cover plates.	Maintenance		Maintenance											
D7	Pavements	Overhauling of courtyard.	25				25									
D9	External constructions on plot	Repair of waste shelter.	2		2											
E43	Draining in substructure	Investigation of existence of the subsurface drain. If there is a subsurface drain maintenance is performed.	3		3											
F12	Foundation walls	Overhaul of the socle wall.	Inc. F31				Inc. F31									
F2	Structural frame elements	Update of the condition study.	6				6									
F2	Structural frame elements	Update of the condition study.	6							6						
F2	Structural frame elements	Update of the condition study.	6										6			
F2	Structural frame elements	Update of the condition study.	6													6
F21	Civil defence shelters	Tightness test of the air raid shelter should be carried every ten year.	5			5										
F31	External walls	Maintenance of the elevations and balconys.	300		300											
F31	External walls	Condition study for the elevations.	15										15			
F32	Windows	Renewal of the windows.	500		500											
F32	Windows	Repair of the solid windows in business premises.	3			3										
F33	External doors	Maintenance of the external doors.	5		5											
F33	External doors	Maintenance of the balcony doors.	Inc. F31		Inc. F31											
F34	External wall complementaries	Maintenance of the balconys.	Inc. F31		Inc. F31											
F34	External wall complementaries	Maintenance of the entrance canopys.	Inc. F31		Inc. F31											
F41	Attic roofs and floors	Renewal of the roof covering.	80	80												
F41	Attic roofs and floors	Renewal of the roof covering in building 2 business premises.	Inc. F41	Inc. F41												
F41	Attic roofs and floors	Condition study for the roof covering.	15							15						
F43	Roof complementaries	Tightness test of the lead-ins and roof installations.	Inc. F41	Inc. F41												
F6	Internal surfaces	Analysis of asbestos and detrimental elements.	6			6										
F6	Internal surfaces	Cost reserve for partial renovation of the sanitary cabins.	400					400								
F6	Internal surfaces	General overhaul of the sauna in building 1.	30					30								
F6	Internal surfaces	Cost reserve for maintenance of the common surface structures.	50										50			
		Structural elements in total	**1463**	80	810	14	31	430	0	21	0	0	71	0	0	6
2. MECHANICAL AND AUTOMATION SYSTEMS																
G13	Room heaters and other heat dissipation	Renewal of recirculation fans in entrance tambours.	15									15				
G2	Water and sewage services	Condition study of the water and sewage network.	6													6
G23	Sewage treatment systems	Renewal of cut-off valves in water supply network.	10							10						
G31	Air-handling units	Renewal of exhaust air handling- units and cleaning and readjustment of the air flows.	30				30									
G31	Air-handling units	Renewal of exhaust air handling- units and cleaning and readjustment of the air flows. The task is divided into two parts for years 2019 and 2020.	30					30								
G31	Air-handling units	Renewal of roof exhaust fan.	10				10									
G33	Ducts	Inside cleaning of the ducts and readjustment of the air flows.	Inc. G31				Inc. G31									
G41	Refrigeration plant	Renewal of split-unit.	5	5												
J6	Building automation systems	Renewal of the HVAC-notification board.	5	5												
		Mechanical and automation systems in total	**111**	10	0	0	40	30	0	10	0	15	0	0	0	6
3. ELECTRICAL SYSTEMS																
H1	Electrical systems, general information	Periodic inspection of electrical systems.	1					1								
H1	Electrical systems, general information	Renewal of electrical blueprints.	3		3											
H22	Main distribution board of electricity	Renewal of main distribution board and risers.	30										30			
H22	Distribution boards under 1000 V	Renewal of froup switchgears during the maintenance of the apartments.	80					80								
H33	Cable flashing	Insulation of the cable lead-through.	1	1												
H45	Lighting distribution	Renewal of the lighting as a part of apartment renovation.	100					100								
H51	Lighting fixtures	Renewal of the lighting in sauna premisis and air raid shelters.	10										10			
H51	Lighting fixtures	Renewal of the lighning in business premisis.	30										30			
H51	External lighting fixtures	Renewal of wall light fittings and lighting poles.	10			10										
H62	Equipment related to electric installations	Renewal of sauna stove and electric blower in building 1	5										5			
H62	Equipment related to electric installations	Renewal of electric blower in building 2	1											1		
H62	Equipment related to electric installations	Renewal of sauna stove and electric blower in building 3	5												5	
H62	Equipment related to electric installations	Renewal of electric blower in building 4	1													1
H62	Equipment related to electric installations	Partial renewal of apartment saunas in building 1	3											3		
H62	Equipment related to electric installations	Partial renewal of apartment saunas in building 2	6												6	
H62	Equipment related to electric installations	Partial renewal of apartment saunas in building 3	9													9
H62	Equipment related to electric installations	Partial renewal of kitchen equipments	5										5			
J3	Sound reproduction and signalling systems	Renewal of door phones	20		20											
F81	Lifts	Building 1: Lift renovation.	50										50			
F81	Lifts	Building 2: Lift renovation.	50											50		
F81	Lifts	Building 3: Lift renovation.	100												100	
F81	Lifts	Building 4: Lift renovation.	50													50
		Electrical systems in total	**570**	1	23	10	0	181	0	0	0	0	130	54	111	60
		Conditional risks and repair needs (2016 - 2028) in total	**0 2144**	**0 91**	**0 833**	**0 24**	**0 71**	**0 641**	**0 0**	**0 31**	**0 0**	**0 15**	**0 201**	**0 54**	**0 111**	**0 72**

7.3 Energy Efficiency Potential Analysis of Long Term Renovation Plan in Case Buildings 1

After making the LTP for the real estate the new energy service proceeds to choosing the LTP task to the further calculation. As seen from Table 8, there are 55 different tasks in the LTP proposal. We can now overrule task like for example, update of the condition assessment, repair of the waste shelter, renewal of the cut-off valves, insulation etc. because they do not have, or have a minor effect on the energy consumption of the building. It is also possible to overrule tasks related to special systems like lifts, door phones, ovens, etc. because of the complexity of the system or because their energy usage has more to do with behavior habits of the tenants.

From the 55 different tasks 13 comes to the energy analysis, which leads to 4 different energy calculations. These are a renewal of elevations and roof covering, replacement of the windows and renewal of the air condition fans. In Table 9, all the chosen LTP tasks of the calculation phase are presented.

Table 9. LTP tasks chosen to the energy calculation

T-90 T-90	Structure / System	Repair	Costs 1000 € (VAT 0%) Total	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
1. STRUCTURAL ELEMENTS																
F31	External walls	Maintenance of the elevations and balconys	300		300											
F32	Windows	Renewal of the windows	500		500											
F32	Windows	Repair of the solid windows in business premises	3			3										
F33	External doors	Maintenance of the external doors	5		5											
F33	External doors	Maintenance of the balcony doors	Inc. F31		Inc. F31											
F34	External wall complementaries	Maintenance of the balconys	Inc. F31		Inc. F31											
F41	Attic roofs and floors	Renewal of the roof covering	80	80												
2. MECHANICAL AND AUTOMATION SYSTEMS																
G31	Air-handling units	Renewal of exhaust air handling- units and cleaning and readjustment of the air flows.	30				30									
G31	Air-handling units	Renewal of exhaust air handling- units and cleaning and readjustment of the air flows. The task is divided into two parts for years 2019 and 2020	30					30								
3. ELECTRICAL SYSTEMS																
H45	Lighting distribution	Renewal of the lighting as a part of apartment renovation.	100					100								
H51	Lighting fixtures	Renewal of the lighting in sauna premisis and air raid shelters.	10										10			
H51	Lighting fixtures	Renewal of the lighning in business premisis.	30										30			
H51	External lighting fixtures	Renewal of wall light fittings and lighting poles.	10			10										

In this case real estate, there are no consumption details or energy certification available. Also the maintenance manual does not give any valid information about the devices or structures used in the building. This why the minimum level of the U-values demanded in the buildings construction year for the structures and windows are used in the calculation tool for the baseline consumption calculations. The real estate has 7 extract fans, which are original from the building year 1989. During the site visit, information about the fans was manged to receive. The fans are working 24 hours a day in full speed mode and from the fans data labels the electrical power of the fan motors were found. The electricity powers of the fans are presented in the Table 10.

Table 10. Fans electricity power

	Power(kW)
Building 1	
PF1	0.45
PF2	0.55
Building 2	
PF1	0.55
PF2	0.55
Building 3	
PF1	0.45
PF2	0.45
Building 4	
PF1	0.45

It is assumed that the fans are designed according to the building regulations in 1989 when there was no regulation for the SFP number of the fans, but the exhaust air volume had to be at least $0.35\frac{\frac{dm^3}{s}}{m^2}$ accepting also the infiltration air flow of 0.1-0.2$\frac{1}{h}$. In calculations, the exhaust air flows are approximated without knowing the actual flows and with these approximations the the SFP number to the fans are calculated. These results are introduced in Table 11.

Table 11. Calculated air flows

	Flow(m^3/s)	SFP
Building 1		
PF1	0.219	2.05
PF2	0.219	2.51
Building 2		
PF1	0.293	1.88
PF2	0.293	1.88
Building 3		
PF1	0.433	1.04
PF2	0.433	1.04
Building 4		
PF1	0.404	1.11

The new building regulation states that the maximum SFP for exhaust fans are 1.0kW/(m^3/s). This gives a saving potential presented in Table 12. It is assumed that the fans are running 8760 hours a year with full speed.

Table 12. Energy consumption of the fans

	Flow(m^3/s)	SFP	Energy(kWh)	New SFP	Energy(kWh)	Savings(kWh)
Building 1						
PF1	0.219	2.05	3942	1	1918	2024
PF2	0.219	2.51	4818	1	1918	2900
Building 2						
PF1	0.293	1.88	4818	1	2567	2251
PF2	0.293	1.88	4818	1	2567	2251
Building 3						
PF1	0.433	1.04	3942	1	3793	149
PF2	0.433	1.04	3942	1	3793	149
Building 4						
PF1	0.404	1.11	3942	1	3539	403
					In total	**10127**
					Percentual	**33.5 %**

It is important to keep in mind that the flows and SFP-numbers for the old fans are estimates and for better results, the actual flows should be measured. Also the powers used in the calculation are not very accurate, because it does not take any efficiency's into account. This is why the savings estimated with this kind of calculations cannot be used as true facts before really measuring the actual powers and flows of the fans. These calculations can be used as key figures of what will happen to the energy consumption of the fans in bigger scale when they are renovated.

Next on the list is the renewal of roof covering, windows and elevations. The effect of these renovations is calculated with the calculation tool. First, the baseline for the energy consumption in all four buildings is calculated to achieve the level where to compere the result of renewal. For this, first, the areas according to the buildings orientation are calculated. The results are shown in Table 13.

Table 13. The areas of the four buildings

		Area[m^2]						
	Height [m]	Building	North wall	South wall	East wall	West wall	Ground floor	Roof
Building 1	12	1475	252	252	264	264	462	462
Building 2	12	1973	132	132	408	408	374	374
Building 3	18	2912	666	666	216	216	444	444
Building 4	12	1357	312	312	168	168	364	364

The window areas for every wall are presented in Table 14.

Table 14. Window areas

	Window area[m^2]			
	North wall	South wall	East wall	West wall
Building 1	120	120	135	135
Building 2	17	40	100	150
Building 3	220	220	100	100
Building 4	82	50	50	102

For structural element the U-values need to be approximated, using the building year 1989 and the Table 2. This gives the U-values for:

- External wall, $0.28\frac{\mathrm{W}}{\mathrm{m^2K}}$
- Base floor, $0.36\frac{\mathrm{W}}{\mathrm{m^2K}}$

- Roof, $0.22\frac{\mathrm{W}}{\mathrm{m^2K}}$
- Windows, $2.1\frac{\mathrm{W}}{\mathrm{m^2K}}$
- q_{50} value, $17\frac{\mathrm{m^3}}{\mathrm{s}}/\mathrm{m^2}$

Then the g-value of the old windows is approximated. It is approximated to be 0.60, and the share of the window framework is 0.2 and the density of sun covering is 1.

For the heat loads the used values are:
- Humans, $6\frac{\mathrm{W}}{\mathrm{m^2}}$
- Equipment, $3\frac{\mathrm{W}}{\mathrm{m^2}}$, because the tenants pay this on their own and it is approximated the heat load from the equipment is very low.
- Lighting $5\frac{\mathrm{W}}{\mathrm{m^2}}$
- Other equipments $1\frac{\mathrm{W}}{\mathrm{m^2a}}$

Other options added to the calculation tool are that the building is heated with district heating, the ventilation system is mechanical exhaust air. The designed air current is set to zero in the calculation tool as well as cooling and heat recovery because they do not exist in the building.

The calculation needs a general rules for the utilization rates. In the calculation tool, the used utilization rate is achieved from the Finnish building regulation. The utilization rates (Finnish Ministry of the Environment, 2016, p. 9) for the apartment buildings in the calculations are presented in Table 15.

Table 15. Used utilization rates for apartment buildings

	Utilisation rates							
	Air conditioning (Sup. and Exh.)		Lightning		Devices		People	
time (h)	Working day	Weekend	Working day	Weekend	Working day	Weekend	Working day	Weekend
1	1	1	0.1	0.1	0.6	0.6	0.6	0.6
2	1	1	0.1	0.1	0.6	0.6	0.6	0.6
3	1	1	0.1	0.1	0.6	0.6	0.6	0.6
4	1	1	0.1	0.1	0.6	0.6	0.6	0.6
5	1	1	0.1	0.1	0.6	0.6	0.6	0.6
6	1	1	0.1	0.1	0.6	0.6	0.6	0.6
7	1	1	0.1	0.1	0.6	0.6	0.6	0.6
8	1	1	0.1	0.1	0.6	0.6	0.6	0.6
9	1	1	0.1	0.1	0.6	0.6	0.6	0.6
10	1	1	0.1	0.1	0.6	0.6	0.6	0.6
11	1	1	0.1	0.1	0.6	0.6	0.6	0.6
12	1	1	0.1	0.1	0.6	0.6	0.6	0.6
13	1	1	0.1	0.1	0.6	0.6	0.6	0.6
14	1	1	0.1	0.1	0.6	0.6	0.6	0.6
15	1	1	0.1	0.1	0.6	0.6	0.6	0.6
16	1	1	0.1	0.1	0.6	0.6	0.6	0.6
17	1	1	0.1	0.1	0.6	0.6	0.6	0.6
18	1	1	0.1	0.1	0.6	0.6	0.6	0.6
19	1	1	0.1	0.1	0.6	0.6	0.6	0.6
20	1	1	0.1	0.1	0.6	0.6	0.6	0.6
21	1	1	0.1	0.1	0.6	0.6	0.6	0.6
22	1	1	0.1	0.1	0.6	0.6	0.6	0.6
23	1	1	0.1	0.1	0.6	0.6	0.6	0.6
24	1	1	0.1	0.1	0.6	0.6	0.6	0.6

Because all of the case buildings are almost the same in shape and equipment level, the used starting values are the same for all of the four buildings. For basic energy consumption levels, the results from the calculation tool are presented in Table 16:

Table 16. Base level, case 1

	Heating [kWh]	Electricity [kWh]
Building 1	206282	34143
Building 2	168046	45671
Building 3	305580	67407
Building 4	154497	31412

The first renovation in the energy service LTP plan is the renewal of roof covering. The U-value of the roof must be according to nZEP $0.09\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}$. After this renewal, the energy consumption is calculated with the calculation tool. The results are presented in Table 17:

Table 17. Renovation of roof covering

After renovation of roof covering	Heating [kWh]	Electricity [kWh]	Percentual change in Heating	Percentual change in electricity
Building 1	199373	34143	3.3 %	0.0 %
Building 2	162623	45671	3.2 %	0.0 %
Building 3	299005	67407	2.2 %	0.0 %
Building 4	149080	31412	3.5 %	0.0 %

Then, the LTP has a renewal of windows and elevations. In nZEP regulations the U-value required for windows are $1.0\frac{\mathrm{W}}{\mathrm{m^2K}}$ and for exterior walls $0.17\frac{\mathrm{W}}{\mathrm{m^2K}}$. These are calculated as a combined change, because the renovation is going to be done at the same time, so the change is simultaneous. The effect to the energy consumption according to the calculation tool is presented in Table 18.

Table 18. Renovation of elevations and windows

After renovation of elevations and windows	Heating [kWh]	Electricity [kWh]	Percentual change in Heating	Percentual change in electricity
Building 1	130958	34143	36.5 %	0.0 %
Building 2	117121	45671	30.3 %	0.0 %
Building 3	207831	67407	32.0 %	0.0 %
Building 4	105898	31412	31.5 %	0.0 %

For comparison, the effect on energy consumption is also calculated separately with the calculation tool. The results are presented separately in Table 19.

Table 19. If the windows and elevation are renovated separately

Only windows	Heating [kWh]	Electricity [kWh]
Building 1	137510	34143
Building 2	126264	45671
Building 3	221713	67407
Building 4	114327	31412

Only elevations	Heating [kWh]	Electricity [kWh]
Building 1	192408	34143
Building 2	152862	45671
Building 3	284429	67407
Building 4	140355	31412

Then, according to the LTP plan, the lighting renovation is coming in 2020, so the effect of renovating the lighting from the old to the LED-technology is calculated. LED-lamps consume approximately 20 percent of the energy of the old fluorescent lamps. It is assumed that all the energy going to the lamps conduct to the air, so the heat load of the lighting is modified from $5\frac{\mathrm{W}}{\mathrm{m^2}}$ to $1\frac{\mathrm{W}}{\mathrm{m^2}}$ in the calculation tool and the new energy consumption is calculated. Now, the energy consumptions are presented in Table 20.

Table 20. Consumption after renovation of lighting

	After renovation of lightning			
	Heating [kWh]	Electricity [kWh]	Percentual change in Heating	Percentual change in electricity
Building 1	133755	28975	35.2 %	15.1 %
Building 2	120618	38758	28.2 %	15.1 %
Building 3	213360	57203	30.2 %	15.1 %
Building 4	108555	26657	29.7 %	15.1 %

Table 20 clearly shows that the better lamps give less heat load to inside air and that is why the heat demand rises couple percentage from previous action, but on the other hand the electricity consumption drops 15.1 percent.

In Figure 18, the yearly percentual change in energy consumption in the LTP periods is presented, if the LTP tasks calculated before are done according to the LTP plan. From Figure 18, can also be seen the effect of the renewal of the exhaust air fans in buildings 1 and 2, where the savings can be clearly seen from the chart. Thus, the main savings in electricity comes in this case from the change to the LED-lamps.

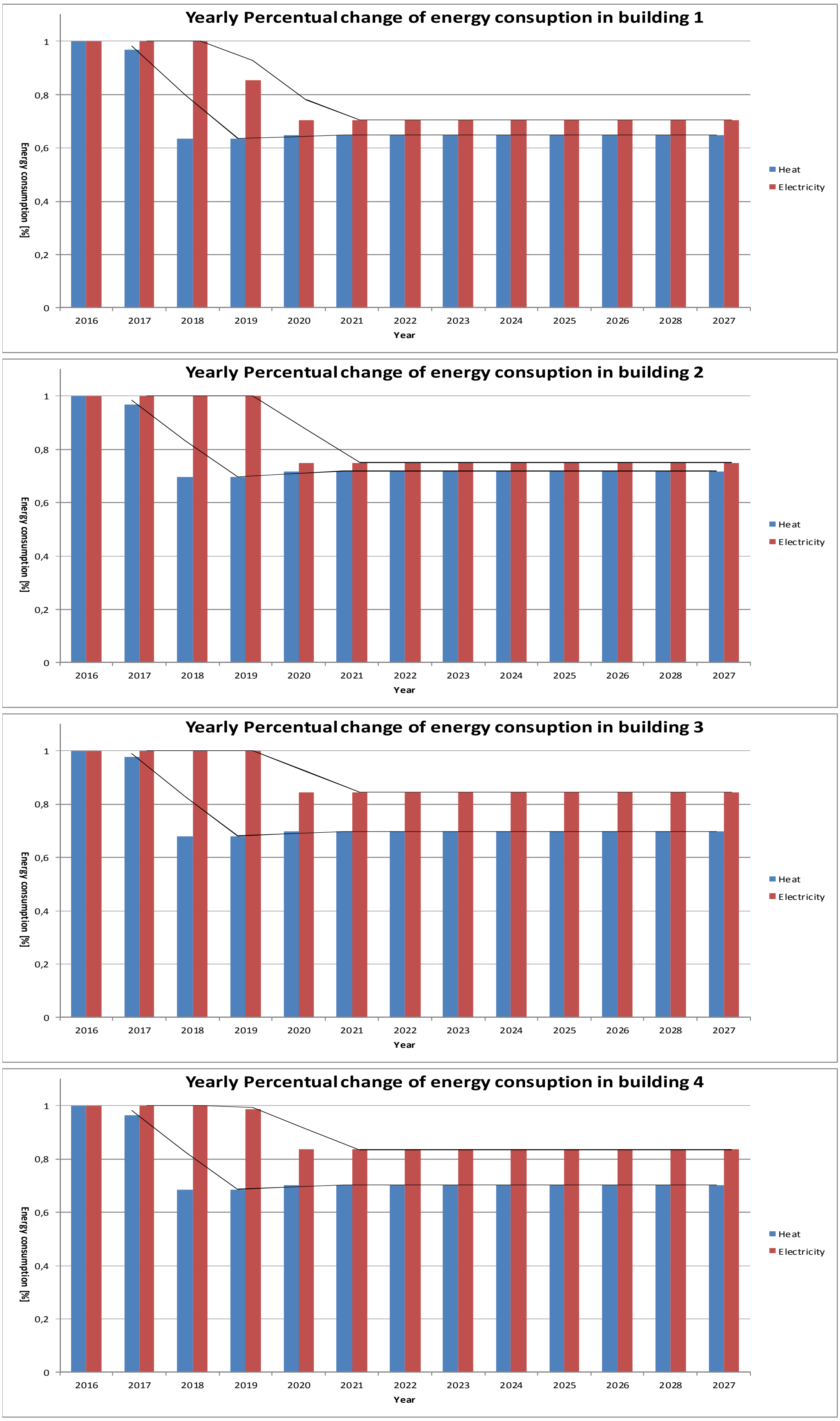

Figure 18. Energy consumptions calculated after the LTP tasks

From the results can clearly be seen that the windows have the biggest effect on the heating cost. This gives us a chance to research the possibility to upgrade the U-value from the minimum of $1.0\frac{\mathrm{W}}{\mathrm{m^2K}}$ to values of $0.8\frac{\mathrm{W}}{\mathrm{m^2K}}$ and $0.65\frac{\mathrm{W}}{\mathrm{m^2K}}$. The prices for windows are obtained from the Ramboll's offer data. The prices are introduced in Table 21.

Table 21. Window prices

Window	Price [€/m2]	U-Value [W/m2K]
Win1	93	1
Win2	114	0.8
Win3	145.6	0.65

The payback periods for the windows is calculated next. The energy consumptions are calculated with the calculation tool and the payback periods with Equations 43-47. It is assumed that the heat price is $0.05\frac{€}{\mathrm{kWh}}$ and escalation of 2 and 4 percent. The investment period was 20 years. The results are introduced in Table 22.

Table 22. The payback periods and net present values

Building 1

	Energy Saving[kWh/a]	Energy saving[€/a]	Investment cost[€]	PBP with 2% escalation[a]	Net present value[€]	PBP with 4% escalation[a]	Net present value[€]
Win1	61863	3093.15	47430	18.5	3147	24.2	-5393
Win2	72725	3636.25	58140	19.5	1318	26.0	-8722
Win3	80737	4036.85	74256	23.2	-8248	33.9	-19394

Building 2

	Energy Saving[kWh/a]	Energy saving[€/a]	Investment cost[€]	PBP with 2% escalation[a]	Net present value[€]	PBP with 4% escalation[a]	Net present value[€]
Win1	36359	1817.95	28551	19.0	1175	25.2	-3844
Win2	42715	2135.75	34998	20.1	-75	27.2	-5972
Win3	47398	2369.9	44699.2	23.9	-5948	35.8	-12491

Building 3

	Energy Saving[kWh/a]	Energy saving[€/a]	Investment cost[€]	PBP with 2% escalation[a]	Net present value[€]	PBP with 4% escalation[a]	Net present value[€]
Win1	77292	3864.6	59520	18.6	3672	24.4	-6999
Win2	90943	4547.15	72960	19.5	1392	26.2	-11163
Win3	101032	5051.6	93184	23.2	-10583	34.1	-24531

Building 4

	Energy Saving[kWh/a]	Energy saving[€/a]	Investment cost[€]	PBP with 2% escalation[a]	Net present value[€]	PBP with 4% escalation[a]	Net present value[€]
Win1	34753	1737.65	26412	18.3	2001	23.9	-2797
Win2	40952	2047.6	32376	19.2	1105	25.5	-4548
Win3	45572	2278.6	41350.4	22.8	-4092	33.0	-10383

As seen from Table 22, there are positive net present values only in windows 1 and 2, if the escalation is 2 percent. Thus there is no reason to invest in better windows from an economic point of view.

In this case real estate the most efficient LTP task studied from an energy perspective as the change of the windows. Virta & Pylsy, 2011 said that windows are the fourth biggest consumer of energy in 1960-70's apartment buildings, and, because the U-value criteria have not changed until 2003 we can assume that the windows are also one of the biggest energy flows in apartment buildings. Also in electricity consumption, the LED-lamps are an efficient investment, if the investment is examined only as a repair or maintenance work.

7.4 Basic Data Building 2

The second case building is from 1939 and is located in Helsinki. It has been renovated once during its lifetime in 1970. The building has 6 storeys above the ground plus a loft and a parking hall is an underground store. The orientation of the building is presented in Figure 18.

Figure 19. Town plan and orientation of the building in case study 2

The building has one agency premise on the ground floor, which has its own split-cooling device. This device is owned by the tenant and not included in the condition survey and LTP plan. The device is also ignored from the calculation for the same reason. It is approximated that the influence of one split unit serving approximately space area of 15-20m^2 has no crucial effects in the calculations.

According to the initial data, the building is renovated in 1970. The biggest renovations made in building after this are discussed in Chapter 7.5.1. The heat distribution center, technical premises and the water main are located in the basement of the building. There are 36 apartments in the building. According to the documents provided by the owner the gross area of the real estate is 4 237$m^2$and heated volume is 12 620m^3. The area and volume information was not verified during the survey.

The basic data of the property and the main systems and structures of the studied property is presented in Table 23.

Table 23. The basic data of the case property 2

Basic data of the property			
Property type	**Apartment building**		
Square area	**4 237**	**m^2**	**Gross floor area**
Building volume	**12 620**	**rm^3**	
Year of construction	**1939**		
Enlargement years	**-**		
Renovation year	**1970**		
Aboveground storeys	**6**		
Underground storeys	**1**		
Structures			
Foundations	**Ground or rock**		
Building frame	**Solid brick and concrete**		
External walls	**Solid brick**		
Facade material	**Plaster**		
Window type	**double-glazed and -framed windowds**		
Roof shape	**Ridged roof**		
Roofing material	**Lock-framed metal-sheeted roof**		
Traffic and parking areas	**None**		
External constructions	**court cover structure**		
Mechanical and automation systems			
Heating plant	**District heating**		
Heat dissipation	**Room heaters, central water-heating**		
Water supply	**Municipal water supply and sewer system**		
Domestic water pipes	**Copper pipes**		
Sewage pipes	**Cast iron pipes, band clamps**		
Pumping stations	**Waste water**		
Ventilation system	**Natural ventilation**		
Cooling plant	**None**		
Cooling system	**None**		
Fire sprinkler system	**None**		
Building automation system	**Separate adjusters and clock timing**		
Electrical systems and transportation equipment			
Electric supply	**Low voltage**		
Distribution of electricity	**Main exchange is 4-conduit system and distribution boards 1-conduit**		
Reserve power unit	**None**		
Kitchen devices	**Small kitchens (kitchenettes)**		
Fire alarm system	**Non-indexed fire alarm system**		
Antenna system	**Connected to cable TV network**		
Burglar detection system	**None**		
Video surveillance system	**None**		
Access control system	**None**		
Lifts	**2 pieces**		

The data presented above describes the main systems and structures of the studied property, if any further information is not given.

7.5 Field Surveying of Building 2 and Long Term Renovation Plan

The field survey took place on 7th of April 2016. In the field survey the condition of the building was studied by the sensory impressions and non-destructive procedures and the LTP is planned for 13 years that is years 2016-2028, because of the client's conation. Random inspections were made to 8 different apartments during the study. Also one retro added agency premises on the ground floor and the parking hall underground of the building were inspected during the survey.

7.5.1 Key Findings During the Site Visit

The structural elements of the building are mainly in satisfactory condition. The estimated repair actions are mainly effects of the ending technical lifetimes and local damage in structures. In the review period, the most significant separate structural repair need is the renewal of the windows in elevation wall, structure of the balconies, roof covering and the sanitary cabins. The building is assumed to be founded on to the ground or rock. The base floor and the intermediate floors are made of concrete and the walls are solid brick. According to the initial data, a condition study has been made for the balconies in 2009. According to the condition study, there is no need for large repairs of the balconies. The external walls are according to visual examination in satisfactory condition. The windows are mainly in poor or satisfactory condition. The windows do not fulfill the today's criteria of energy efficiency and renewal of the windows is recommended during the repair of the window frames. The balcony and external doors are also at the end of their technical lifetime and are recommended to be changed during the window and external wall overhaul. From the initial data and during the site survey, no information about the repairs and maintenance of the roof covering were found. During the site survey, proof about water leakages from the roof covering was found and the general overhaul of the roof covering is recommended.

The HVACA- technologies of the buildings are mainly from the overhaul year 1970, but the heat distribution center is renovated 2012 and it is in good condition. Also the thermostatic radiator valves are from the same period as the heat distribution center. In the review period the most significant separate HVACA repair need is the overhaul of water, sewage and gas networks. The building is connected to the district heating network, which is in satisfactory condition according to the condition study obtained from the initial data. According to the same condition study of the sewage and water network, there are corrosion problems in the network and at some points there is only 28 percent left from the original gauge of the pipes. In the car hall located on the base floor there are two mixed sewage pumps. The pumps are working well according to the maintenance-man, but at the end of their technical lifetime. The renewal of the pumps is designed at the same time with the sewage and water network overhaul. The building has natural ventilation supported by five powered roof ventilators, serving for example, the sauna premises. During the sewage and water network overhaul, it is recommended to clarify the possibility of changing the natural ventilation to mechanical exhaust air. The building does not have any cooling devices except for the one split unit owned by the tenant. However, there are still two old cooling units installed, that are out of usage. The cooling units have served the building cold rooms, which are now changed to warehouses. The building is also connected to the natural gas network and the building's ovens work with natural gas. According to the maintenance-man the natural gas network is from the maintenance year 1970, and it is recommended to be changed at the same time with the sewage and water network.

The real estate’s electrical systems are mainly from 1970 and at the end of their technical lifetime. The most expensive repairs from an electrical point of view come from the renewal of the switchboards, lighting and final circuits. Also the lifts should be renovated at the end of the review period. The building is connected to the 400 volts low voltage network and the apartments have 1-conduit distribution boards from 1970. The lighting in the staircases has been renovated in the 21st century and is in satisfactory condition. In the loft, there are still original lamps from 1939. The lamps installed solid in the apartments are also from the renovation year 1970. All the lamps are suggested to be changed to LED lamps during the overhauls of the electrical systems. The apartment’s ovens are working with natural gas and it is suggested that during the electricity system maintenance a chance to change the oven to electrical one is added.

7.5.2 The Long Term Renovation Plan for Case 2

The LTP plan is made the same way as in the first case study, for the next 13 years. In this case, the biggest overlaps between LTP tasks are the maintenance of water, sewage and natural gas network and the maintenance of the electricity system. The renewal of electricity systems should be carried out at the same time with the overhaul of the water and the sewage network.

The LTP plan for the case study building number two is presented in Table 24. In the table, all the three technical elements are divided into their own tasks and the LTP tasks moving on to the calculation phase of the new energy service ire colored pink. The tasks are chosen because of the author of the thesis think that these LTP tasks have the biggest effect on the buildings energy consumption.

In Table 24, the costs presented are mainly from the book Haahtela, Talonrakennus kustannustieto, 2015 edition. The costs coming to the energy calculations are revised to achieve more accurate costs for example for the windows, but if there is no knowledge of the prices, the costs are calculated with Haahtela and used in the calculations as such.

Table 24. The LTP plan for the second case building

T-90	Structure / System	Repair	Costs 1000 €	(VAT 0%	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
T-90			Total	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
1. STRUCTURAL ELEMENTS																
D7	Pavements	Repair of the asphalt	5		5											
D9	External constructions on plot	Condition study for the court cover	5					5								
D9	External constructions on plot	Cost reserve for maintenance of the court cover	10										10			
D9	External constructions on plot	Repair of the outdoor warehouse	5			5										
F12	Foundation walls	Condition study for the foundations walls and renovation planning	10		10											
F12	Foundation walls	Renewal of the foundation walls	40			40										
F13	Ground floor slabs	Renewal of the ground floor in the parking hall	10								10					
F2	Structural frame elements	Update of the condition study	6													6
F2	Structural frame elements	Update of the condition study	6													6
F2	Structural frame elements	Update of the condition study	6													6
F2	Structural frame elements	Update of the condition study	6													6
F31	External walls	Condition study for the balconys and renovation planning	20		20											
F31	External walls	Local repairs of the elevation of the building	50			50										
F32	Windows	Renewal of the windows	150			150										
F33	External doors	Renewal of the external doors	15			15										
F34	External wall complementaries	Renewal of the balconys	80			80										
F34	External wall complementaries	Condition study for the handrails in balconys and possible repairs	5	5												
F41	Attic roofs and floors	General overhaul of the roof covering	150						150							
F43	Roof complementaries	Installation of snow protection systems in the roof	5	5												
F43	Roof complementaries	Renewal of the roof fittings with the renewal of roof covering	Inc. F41						Inc. F41							
F44	Skylights	Renewal of the skylight windows in roof covering	Inc. F41						Inc. F41							
F6	Internal surfaces	Analysis of asbestos and detrimental elements	5		5											
F6	Internal surfaces	Renovation of the sanitary cabins during general overhaul of the water and sawage network	300							300						
F6	Internal surfaces	Cost reserve for maintenance of the common surface structures	80							80						
		Structural elements in total	**969**	10	40	340	0	5	150	380	10	0	10	0	0	24
2. MECHANICAL AND AUTOMATION SYSTEMS																
G12	Heat distribution	Condition study of the heating network	6											6		
G14	Thermal insulation related to heating	Repairs of the broken insulations	2	2												
G2	Water and sewage services	Project planning of the renewal of the water and sewage services	30						30							
G22	Domestic water installations	Renewal of the water and sewage services	1500							1500						
G23	Sewage treatment systems	Renewal of the waste water pumps	Inc. G22							Inc. G22						
G23	Sewage treatment systems	Renewal of the sand and oil trap wells	Inc. G22							Inc. G22						
G24	Sewer network installations	Renewal of the sawage network	Inc. G22							Inc. G22						
G25	Plumbing fixtures	Renewal of the blumping fixtures	Inc. G22							Inc. G22						
G33	Ducts	Inside cleaning of the ducts and readjustment of the air flows	25	25												
G55	Natural gas system	Renewal of natural gas network	Inc. G22							Inc. G22						
J6	Building automation systems	Renewal of the HVAC-notification board	5	5												
		Mechanical and automation systems in total	**1568**	32	0	0	0	0	30	1500	0	0	0	6	0	0
3. ELECTRICAL SYSTEMS																
H11	Electrical systems, general information	Preventive maintenance work of the electrical systems	1									1				
H22	Main distribution board of electricity	Planning of the renewal of the main distribution centre	10		10											
H22	Distribution boards under 1000 V	Renewal of the main distribution centre	20			20										
H22	Distribution boards under 1000 V	Renewal of the measurement centre	30			30										
H22	Distribution boards under 1000 V	Renewal of the apartments power group centre	60							60						
H31	Cable shelves	Installation of cable routes to the engineering and utily services rooms.	30							30						
H33	Cable flashing	Fire insulatio of the cable lead-ins	2	2												
H44	Power distribution	With renovation of the apartments it is recommended to instal a three-phase final circuit for electrical ovens	40							40						
H45	Lighting distribution	Renewal of the old lighting distribution to the 5-conduit system (TN-C-S)	100							100						
H51	Lighting fixtures	Renewal of the lighting in public spaces	10							10						
H51	Lighting fixtures	Renewal of the apartments lighting	40							40						
H51	External lighting fixtures	Renewal of the outdoor lighting	2										2			
H62	Equipment related to electric installations	Renewal of the automation of the car shelters bascule door	3										3			
H62	Equipment related to electric installations	Renewal of the kitchen equipments	70							70						
H74	Safety lighting	Renewal of the safety lighting	10												10	
J1	Telephone systems	Renewal of the old telephone network with general cabaling system	20							20						
J2	Broadcast reception systems	Renewal of the antenna network	20							20						
J3	Sound reproduction and signalling systems	Renewal of the door buzzer system	20							20						
F81	Lifts	General overhaul of the lift in the A-corridor	50							50						
F81	Lifts	General overhaul of the lift in the B-corridor	50							50						
		Electrical systems in total	**588**	2	10	50	0	0	0	510	0	1	5	0	10	0
		Conditional risks and repair needs (2016 - 2028) in total	**0 3125**	**0 44**	**0 50**	**0 390**	**0 0**	**0 5**	**0 180**	**0 2390**	**0 10**	**0 1**	**0 15**	**0 6**	**0 10**	**0 24**

7.6 Energy Efficiency Potential Analysis of Long Term Renovation Plan in Building 2

In this case, the LTP proposal had 53 different LTP tasks. The amount of the tasks is formed mainly because of the electrical system which was at the end of its technical lifetime. The electrical tasks are connected to each other, instead they are in the LTP proposal as independent tasks for the same year. Seven tasks were chosen into the energy calculations, which leads to 3 energy potential calculations.

This case building has an energy certificate from 2009, which gives a baseline for the energy consumption. The yearly consumption of heating energy was 593 800kWh and the standardized consumption 855 662kWh. The measured electricity usage of the building is 22 834kWh and water consumption $4087\mathrm{m}^3$ meaning that the yearly consumption is $965\frac{\mathrm{l}}{\mathrm{m}^2}$. This knowledge gives a good starting point when we setting a good baseline for the calculation tool. The basic settings of the calculation tool are as follows:

- 8 storeys including the basement and attic floors
- Floor height is 2.9 metres and the gross area is $4237\mathrm{m}^2$
- The set temperature of the ground is 10°C

The wall and window areas to different point of compass and the area of the roof and base floor:

- North, wall area $460\mathrm{m}^2$, window area $125\mathrm{m}^2$
- South, wall area $460\mathrm{m}^2$, window area $62\mathrm{m}^2$
- East, wall area $805\mathrm{m}^2$, window area $144\mathrm{m}^2$
- West, wall area $805\mathrm{m}^2$, window area $220\mathrm{m}^2$
- Ground floor, $700\mathrm{m}^2$
- Roof, $700\mathrm{m}^2$

For structural elements we need to approximate the U-values. It is known that the building had been renovated in 1970, so the U-values given in Table 2, for the year 1970 are applied. This gives:

- External wall, $0.8\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}$
- Base floor, $0.47\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}$
- Roof, $0.35\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}$
- Windows, $2.8\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}$
- g_{50} value, $6\frac{m^3}{s}/m^2$

Then, the g-value of the old windows is approximated. It is g-value is approximated to be 0.71, and the share of the window framework is 0.2 and the density of sun covering is 1.

For heat loads, the calculation uses values of:

- Humans, $6\frac{\mathrm{W}}{\mathrm{m}^2}$
- Equipment, $0\frac{\mathrm{W}}{\mathrm{m}^2}$, because the tenants pay for this on their own and we approximate the heat load from the equipments to be very low.
- Lighting $5\frac{\mathrm{W}}{\mathrm{m}^2}$

- Other equipments, $1\frac{\mathrm{W}}{\mathrm{m^2a}}$

The ventilation system works with gravity, so we set in the calculation tool the designed air current of the air conditioning to zero as well as the cooling and efficiency of the heat recovery, because they does not exist in the building. The case building is heated with district heating.

With these, the basic annual consumption of the building, calculated with the tool are:
- For the heating, 593 798kWh
- For the electricity, 22 795kWh

The results are quite close to the consumptions on the energy certificate so is assumed that the calculation tool gives fairly good answers and the answers can be used as a baseline of the calculations.

The utilization rates of the apartment buildings are the same as in the first case study and presented in Table 15.

Next step is to make the LTP plan and choosing the tasks added to the calculation phase. The chosen tasks are mainly related to the change of the windows, renewal of lighting and maintenance of the roof covering. In Table 25, all the LTP tasks chosen to the calculation phase are presented.

Table 25. LTP tasks chosen to the energy calculation

T-90 Structure / System	Repair	Costs 1000 € (VAT 0%) Total	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
T-90															
1. STRUCTURAL ELEMENTS															
F32 Windows	Renewal of the windows	150			150										
F33 External doors	Renewal of the external doors	15			15										
F41 Attic roofs and floors	General overhaul of the roof covering	150						150							
F43 Roof complementaries	Renewal of the roof fittings with the renewal of roof covering	Inc. F41						Inc. F41							
F44 Skylights	Renewal of the skylight windows in roof covering	Inc. F41						Inc. F41							
2. MECHANICAL AND AUTOMATION SYSTEMS		0	0	0	0	0	0	0	0	0	0	0	0	0	0
3. ELECTRICAL SYSTEMS		0	0	0	0	0	0	0	0	0	0	0	0	0	0
H51 Lighting fixtures	Renewal of the apartments lighting	40							40						
H51 External lighting fixtures	Renewal of the outdoor lighting	2										2			

According to the LTP, the windows, lighting and the roof covering are going to be renovated. From Table 2, can be read that the nZEP U-value limits for roof are $0.09\frac{\mathrm{W}}{\mathrm{m^2K}}$ and for the windows $1.0\frac{\mathrm{W}}{\mathrm{m^2K}}$. In the LTP plan that the change of the windows is planned to be in 2018 and the repair of the roof covering in 2021. Now, firstly the U-values of windows are changed in the calculation tool from $2.8\frac{\mathrm{W}}{\mathrm{m^2K}}$ to $1.0\,\frac{\mathrm{W}}{\mathrm{m^2K}}$.

After the window change, the results from the calculation tool for the heating energy consumption is 473 530 kWh/a. The yearly energy saving is:

E_{heat} = 593 798 kWh − 473 530 kWh = 120 268 kWh, with the U-value of $1.0\frac{\mathrm{W}}{\mathrm{m^2K}}$ for the windows

Then the calculations with the windows with better U-value are done with the calculation tool. The consumptions results with better U-value windows are:

E_{heat} = 593 798kWh − 460 408kWh = 133 408kWh, with the U-value of $0.8\frac{\mathrm{W}}{\mathrm{m^2K}}$

$E_{heat} = 593\ 798\text{kWh} - 450\ 594\text{kWh} = 143\ 204\text{kWh}$, with the U-value of $0.65\frac{\text{W}}{\text{m}^2\text{K}}$

So, with better windows, the achieved energy saving is from 120.3MWh to 146.5MWh. In percentage, the saving potential is then 20.3-24.1 percent.

Next thing is the change of the U-value of the roof covering from $0.35\frac{\text{W}}{\text{m}^2\text{K}}$ to $0.09\frac{\text{W}}{\text{m}^2\text{K}}$ in the calculation tool, in the assumption that the windows have been changed. Then the energy savings with 3 different U-values for the windows are according the calculation tool:

$473\ 530\text{kWh} - 451\ 877\text{kWh} = 21\ 653\text{kWh}$, with the U-value of $1.0\frac{\text{W}}{\text{m}^2\text{K}}$
$460\ 408\text{kWh} - 438\ 828\text{kWh} = 21\ 580\text{kWh}$, with the U-value of $0.8\frac{\text{W}}{\text{m}^2\text{K}}$
$450\ 594\text{kWh} - 429\ 073\text{kWh} = 21\ 518\text{kWh}$, with the U-value of $0.65\frac{\text{W}}{\text{m}^2\text{K}}$

It can be seen, that the renewal of roof covering has almoust the same effect on energy consumption in all three window cases so it can be said that the energy saving potential of the renewal of roof covering is 21.5MWh. In percentage, the saving potential is then 3.6 percent of the original energy consumption.

The third energy calculation concerns the lighting of the building. Most of the lighting comes from the old lamps from the 1970's, which are now planned to be changed to LED lamps in 2022. In the calculation tool the heat load from the lamps was set on $5\frac{\text{W}}{\text{m}^2}$, it is assumes that the LED lamps consume 20 percent energy of the old lamps and all the used energy of the lamps is going to heat load. The heat load from the calculation tool is changed to $1\frac{\text{W}}{\text{m}^2}$.

Now, the new energy consumptions are according the calculation tool with LED-lamps and at the state that the windows have been changed to U-value of $1.0\frac{\text{W}}{\text{m}^2\text{K}}$ and the roof covering is renovated to U-value of $0.09\frac{\text{W}}{\text{m}^2\text{K}}$:
$E_{\text{heat}} = 461\ 229\text{kWh}$
$E_{\text{elect}} = 7\ 949\text{kWh}$

This means that the heat consumption has raised 9 352 kWh and electricity consumption has dropped 14846kWh, so the total energy saving potential is 5494 kWh. In percentage, the backfire potential is from the previous heat energy consumption 2.1 percent and the energy saving potential in electricity 65.1 percent. In Figure 19, can be seen the percentual change in energy consumption according the results from the calculation tool, if the LTP tasks are made with minimum criteria and in Table 26, the percentual change of the energy consumption of the building after every LTP action.

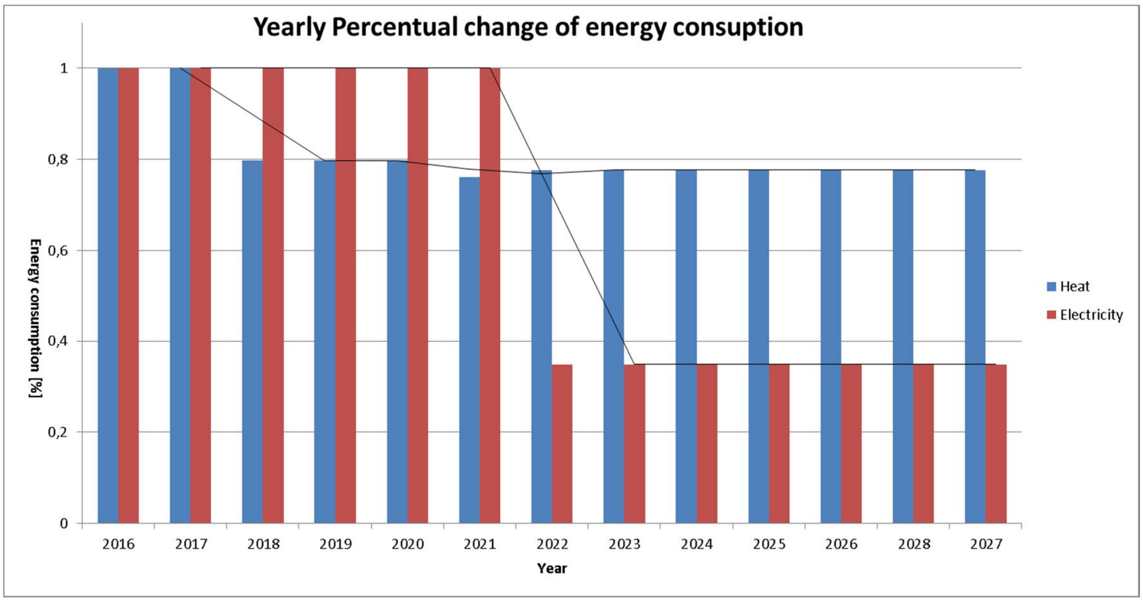

Figure 20. Energy consumption after LTP tasks

Table 26. Percentual effects to the buildings energy consumption after implemented LTP actions

After all renovations with 0.65 U-value windows

	Heating [kWh]	Electricity [kWh]	Percentual change in Heating	Percentual change in electricity
Baseline	593798	22795		
After window renovation	450594	22795	24.1 %	0.0 %
Renovation of roof covering	429073	22795	27.7 %	0.0 %
Renewal of lighting	438084	7949	26.2 %	65.1%

After all renovations with 0.8 U-value windows

	Heating [kWh]	Electricity [kWh]	Percentual change in Heating	Percentual change in electricity
Baseline	593798	22795		
After window renovation	460408	22795	22.5 %	0.0 %
Renovation of roof covering	438828	22795	26.1 %	0.0 %
Renewal of lighting	448043	7949	24.5 %	65.1%

After all renovations with 1.0 U-value windows

	Heating [kWh]	Electricity [kWh]	Percentual change in Heating	Percentual change in electricity
Baseline	593798	22795		
After window renovation	473530	22795	20.3 %	0.0 %
Renovation of roof covering	451877	22795	23.9 %	0.0 %
Renewal of lighting	461229	7949	22.3 %	65.1%

In this case building, there is an LTP task for changing the windows, which can be up-graded to even better than the minimum U-value level of $1.0\frac{\mathrm{W}}{\mathrm{m^2K}}$. The payback periods for better windows are calculated next. The prices for the better windows are obtained from the Ramboll's offer data introduced in Table 21.

Now, we can calculate the payback periods for the windows. We again assume that the heat price is 0.05€/kWh and we use an escalation of 2 and 4 percent. The investment period is 20 years. The energy consumptions are calculated with the calculation tool and the payback periods with Equations 43-47. The results are presented in Table 27.

Table 27. The payback periods

	Energy Saving [kWh/a]	Energy saving [€/a]	Investment cost [€]	PBP with 2% escalation [a]	Net present value[€]	PBP with 4% escalation [a]	Net present value [€]
Win1	120268	6013.4	51243	9.4	47085	10.6	30481
Win2	133408	6670.4	62814	10.5	46257	12.1	27839
Win3	143204	7160.2	80225.6	12.8	36854	15.2	17084

As we can see from Table 27, the PBP for the windows is settling to the level where the payback period is between 10-15 years. However, if we analyse the investments with the net present value, we can clearly see that the windows with U-value of $1.0\frac{\mathrm{W}}{\mathrm{m^2K}}$ are the best option if the investment time is 20 years. If the investment period was 30 years, the windows with U-value of $0.8\frac{\mathrm{W}}{\mathrm{m^2K}}$ would come very close to ones with U-value of $1.0\frac{\mathrm{W}}{\mathrm{m^2K}}$, but the windows with the best U-value is still the most unprofitable investment.

8 Results of the Study

As we can see from the case study results, the LTP tasks taken to the calculation phase of the new energy service are mainly structure, lighting or ventilation related. In the two case studies, only the second one had a minimum level of basic initial data available, which made the case studies hard to carry out, because the baseline of energy consumption was hard to set and more detailed analyse of the structural elements and technical equipment was based only on visions and equipment labels, if the labels still existed. In Figure 20, the heat balance of a typical Finnish apartment building according to Virta & Pylsy is presented.

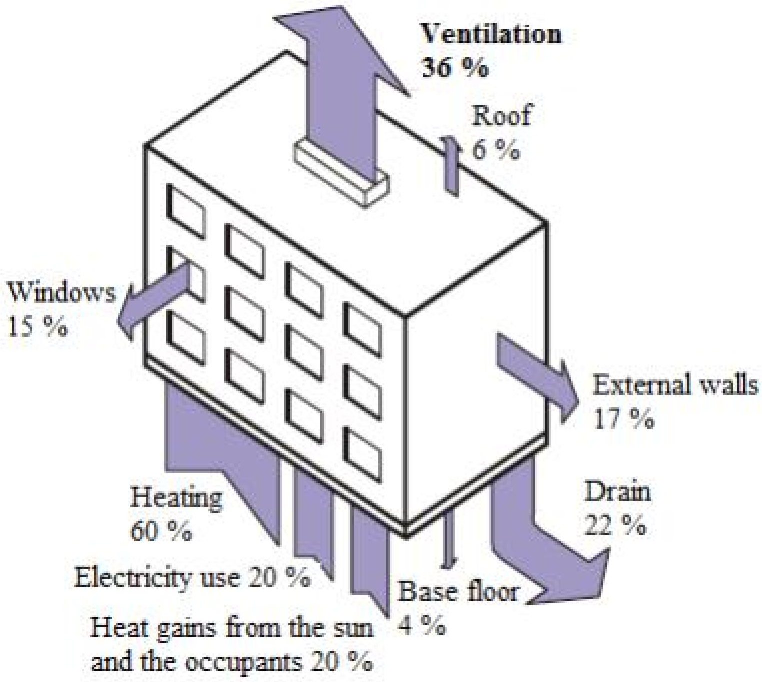

Figure 21. Heat balance of a typical Finnish apartment building (Adopted from Niemelä, 2015, Retermia, 2014a, Virta & Pylsy, 2011, p.19)

From the figure, it can be seen that the biggest energy flows from the building, according to Virta & Pylsy, 2011 are the same things that were selected to the calculation phase of the new energy service excluding the drain. This makes the decisions of the tasks chosen to the calculation phase more reasonable and gives a good proof that the calculation concentrated on the right technical systems when the new service wanted to have a rough estimate of the effects in the name of energy consumption of the apartment building during the LTP tasks.

In both of the cases, the renovation of the windows and roof gives us a saving potential of approximately 25 percent in heating energy. This is in a scale if we compere the results to the previous studies in energy consumption of apartment buildings, but still, it have to be remembered, that the solutions given by the tool are good estimates and in case the overhaul is actually done, the specific heat model should be made to achieve more accurate knowledge and cost optimal solutions for the renovation.

In the case studies, the air condition systems were old fashioned gravity based air conditioning or mechanical exhausts. These systems are hard to model with the used calculation tool, because the air flows were unknown and that is why the evaluation of the renewal of exhaust fans in the first case study was made by their own. The electricity consumption of the air conditioning in the first case is calculated with big conservatively of the power used by the machines. This is obviously the weakest part of the calculation tool, because typically due diligence does not upgrade the systems so it makes the energy balance modelling of the air condition very hard, when there is no mechanical air conditioning. Mechanical exhaust air conditioning can be calculated separately as seen in the first case study or it can be added to the consumption of the other mechanical instruments, if the powers of the fans are known.

The calculation and estimates of the energy consumption are quite rough as planned, but it gives fairly realistic assumptions of what will happen if the LTP tasks are carried out as submitted to the LTP plan. The calculation tool calculates the building's energy balances fast and efficiently. It gives solutions without any needing to make a more detailed dynamic model of the case building with for example Ida-Ice or another simulation tool. This gives the person responsible for executing the new energy service the wanted elasticity to perform the calculations, analyse it and transfer the obtained solutions to reporting template in only a few working hours.

In the case studies, the biggest problems with the calculation come from the missing initial data, for example, about missing data information and technical drawings, which could give the needed values for more accurate calculations. Also the time schedule of the normal TDD condition survey gives a challenge, because normally it is ready just before the project deadline, which means that the calculation phase of the new energy service does not have enough time resources before the project deadline. This problem can be avoided if the project manager remembers to reserve a working day or more for the service and quality inspections. The services also require good communication between the experts to achieve the needed LTP data on time and to be more accurate with the technical solutions in the building at the moment.

The payback periods and the upgrade comparison in the two cases were made only for the windows. In both of the cases the upgrade from the requisite level to even better was not cost-effective from an economic point of view. If the investments are studied more from the energy consumption or E-value perspective, the investment could be more reasonable but these decisions are in the responsibility of the owner. The comparison of the fans would be more reasonable, if the initial data gave more details about the operating times and air flows. From the case buildings, only one had the mechanical exhaust air as an air-conditioning system. In this case, it was hard to add a frequency converter to the calculations, because the system typically operates only with full speed and now the situation was that the air flows where unknown. This why it was very hard to dimension the new fan and add frequency converters to the calculation case with only rough estimates about the air flows. This means that the potential savings obtained from the use of the frequency converter are easily lost. This is because of the potential of adjusting the fan with the frequency converter cannot be used, or even more assumptions are needed to add to the calculations. In the same case building, heat recovery could be added to the exhaust air calculations, but the case building has a technical problem where to transfer the heat to, because the heat distribution centre was too far away from the fans and the centre was serving all of the 4 buildings. In this case, it was estimated that the potential from the heat recovery would be lost because of the big transfer distances.

In the case studies, the new energy service as a part of technical due diligence is flexible and easy to use with LTP plan, but it has its own problems described earlier. The dialogue between the consult and orderer of the new service needs to be on a good level, because it is easier to calculate the specific tasks into the report when the intent of customer is known and their willingness to system upgrades or bigger renovations is in knowledge.

According to the knowledge gained from the case studies, the new energy service can be performed as planned with minor changes to actions and time schedules during the technical due diligence process. The shortage of initial data and information about the old technical implementations made the case studies harder than excepted. However a rough estimate about the energy consumption was received, with the assumption that the building is built with the minimum requirements of the building or renovation year.

9 Conclusions and Discussion

The aim of the thesis was to create a new energy service as a part of the technical due diligence to be added into the value adding services of due diligence in Ramboll Finland Oy. The idea of the new service was to show the customer the energy saving potential of the LTP tasks and the possible backfire potential of the task or system upgrades proposed in the LTP. The typical concept of the real estate due diligence drew the new service to the direction of cost efficient execution with tight schedule. This is why the heat dynamic model of the building was made with Microsoft Excel and Visual Basic. The calculation model was designed not to give so detailed, but still accurate enough estimates of the energy consumption of the building. To do this, we needed to adopt an efficient calculation tool, which could model the apartment building as a heat dynamic model, but still be very fast, because the due diligence projects are done under a very tight schedules and low working hours, the detailed and time spending simulation are out of the scope.

The benefit of the dynamic modelling is the bigger accuracy of the calculation compared to monthly methods. The dynamic modelling gives extra value to the calculation of the stationary state when the calculation takes into account the thermal loads of the building and the changing outdoor conditions in rather small time step. The dynamic simulation also enables the possibility for efficient and accurate comparison between different building elements and their impact to buildings energy consumption in smaller time scale, for example one month or one day. Indoor air quality is also one aspect that favourites the dynamic modelling. With dynamic model, for example, the indoor air temperature can be set as constant and that how the cooling and heating need of the building can be calculated more accurate, when the calculations takes into account the short-term thermal loads. In cases where the need of the cooling power is a must, the dynamic modelling is regarded the only relevant option to obtain good and reliable results. (Sirén, 2015) The dynamic calculation also enables the potential to evolve the calculation tool for example to the office buildings, where the cooling is typically used to ensure indoor air quality and temperature during summer season.

The selected calculation tool responded to the need well. It was fast and gave solutions with needed accuracy. Nevertheless, the selected tool had a couple problems which should be taken into account when the service is developed further. Most of the problems related to the air conditioning of the old buildings and how to take the heat demand and mechanical exhaust air condition into account in the calculation tool. But on a bigger scale the calculation tool operating the heat nodal points is a simple and efficient way to estimate the effects of LTP tasks.

In the new energy service, the author chose the calculated tasks in the case studies. The chosen tasks were related to the structures of the building, air condition and lighting. These tasks are, according to the previous studies most typical energy renovations and that is why they are a good to choose to the calculation phase, but this is only the case when the case building is old enough and the structural elements are at the end of their technical lifetime. In newer buildings, the LTP task list is much shorter and the energy efficiency on the other hand is in a better situation, because of the tightened building regulations. This is why it is important to investigate in further studies if there is any business potential for this kind of service when the apartment building is built in 21st century and there are almost none of LTP task planned in the next 10 years.

The new energy service can be performed as planned with minor changes to the actions and time schedules during the technical due diligence process. The shortage of initial data and information about the old technical implementations must be taken into account in further development and cases. Access rights to the maintenance manuals, energy certificates, old LTPs and technical drawings should be arranged by the parties making the real estate trading in reasonable time during REDD process.

The new service was develop to apartment buildings mainly because of the case buildings availability at the time of the thesis was started. Typically the real estate transactions are office or logistics buildings, so in the further studies the calculation tool and the new process should be transferred to fulfil the needs of the cases where the real estate is an another kind of building than apartment building. This provides a bigger segment in the TDD market for the service, when it can be marketed to different kind of buildings.

After further development of the calculation tool, the modernisation and upgrades of the e.g. air conditioning system or cooling can be also taken into account better and the possible rebound of the energy consumption can be calculated and shown to the customer. This also gives the customer a responsibility to think, what the value of better living environment and indoor air quality is, while the customer is concerning the investment in upgrade of the systems that are not profitable in an economic point of view.

All the calculations are done in trust that the new building regulations under circulations of comments, concerning the energy efficiency of a new building are also going to affect the reconstruction of the buildings. Because of the character of REDD the thesis did not take renewable energy sources under investigation. Renewal energy could be added to the service in a form of ground heat pumps and solar panels as an individual subservice, only calculated when the customer has a conation towards renewal energy in the case building. It can be carried out as a development project of the new service, if there is a market potential for this kind of service during the TDD cases.

The thesis, does not take any standpoint to the economical or collative effects of the coming regulations in reconstruction of the building, which could be a good research topic in perspective of energy and public economy. The new nZEB regulations also have an effect to the total energy consumption of the buildings and if LTP plans are implemented with nZEB regulations, it could harness a big energy efficiency potential in the building stock in Finland.

Furthermore, it is worth of nothing, that technical due diligence services are widely provided, but no-one has a service that gives any kind of information about the benefits or rebound effects of the LTP action plans made in the condition assessment phase of the TDD. This study gives new information about the future energy efficiency potential of the building and shows the benefits gained from the implementation of the LTP, when the typical LTP just gives a rough estimate about costs coming from renewal of the old technical systems.

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Appendix 1. Finnish Ministry of the Environment 2016. Asetus uuden rakennuksen energiatehokkuudesta. Luonnos 14.3.2016. Pages 4-5.

Appendix 1. Finnish Ministry of the Environment 2016. Asetus uuden rakennuksen energiatehokkuudesta, pages 4-5

Loma-asumiseen suunniteltavaa pientaloa ei koske energiatehokkuuden vertailulukuvaatimus.

Massiivipuurakennusta suunniteltaessa saadaan edellä 1 momentissa esitetyt vertailuluvun raja-arvot ylittää käyttötarkoitusluokan 1 a – e rakennuksessa 15 prosenttia ja muussa rakennuksessa 10 prosenttia.

Rakennuksen energiatehokkuuden vertailuluvun raja-arvo käyttötarkoitusluokassa 1 f saadaan ylittää 5 prosenttia, kun rakennus on kytketty lämmitysjärjestelmään, jossa lämpö johdetaan rakennuksen ulkopuolisilla lämpöputkilla yhteisestä lämmönsiirtimestä tai lämmöntuottolaitteesta kolmeen tai useampaan rakennukseen.

6 §
Rakennuksen osan vertailuluvun vaatimustaso

Jos rakennukseen suunnitellaan eri käyttötarkoitusluokkiin kuuluvia osia, sovelletaan kuhunkin eri osaan, mitä pykälässä 5 on säädetty vertailuluvun raja-arvon vaatimuksesta kunkin käyttötarkoitusluokan osalta. Jos rakennuksen osan lämmitetty nettoala on alle 10 prosenttia koko rakennuksen lämmitetystä nettoalasta, osa voidaan laskea pääasialliseen käyttötarkoitukseen kuuluvaksi.

7 §
Rakennuksen lämpöhäviö

Rakennuksen lämpöhäviö on rakennuksen vaipan, vuotoilman ja ilmanvaihdon yhteenlaskettu lämpöhäviö. Rakennuksen lämpöhäviö saa olla enintään yhtä suuri kuin vertailuarvoilla rakennukselle määritetty vertailulämpöhäviö.

Rakennuksen lämpöhäviön määräystenmukaisuus osoitetaan erikseen rakennuksen lämpimille ja puolilämpimille tiloille. Erityisen lämpimät ja jäähdytettävät kylmät tilat lasketaan kuten lämpimät tilat.

Loma-asumiseen suunniteltavaa pientaloa, joka on tarkoitettu käytettäväksi vuodessa neljä kuukautta tai enemmän, koskevat rakennuksen lämpöhäviön osalta vain rakennuksen vaipan lämpöhäviölle asetetut vaatimukset.

8 §
Rakennuksen vaipan lämpöhäviö

Rakennuksen vaipan lämpöhäviö määritetään laskemalla yhteen eri rakennusosien pinta-alan ja rakennusosan lämmönläpäisykertoimien tulot kaavalla:

$$\sum H_{joht} = \sum (U_{ulkoseinä}\, A_{ulkoseinä}) + \sum (U_{yläpohja}\, A_{yläpohja}) + \sum (U_{alapohja}\, A_{alapohja}) + \sum (U_{ikkuna}\, A_{ikkuna}) + \sum (U_{ovi}\, A_{ovi})$$

jossa:
$\sum H_{joht}$ on rakennuksen vaipan lämpöhäviö, W/K;
U on rakennusosan lämmönläpäisykerroin, W/(m²K);
A on rakennusosan pinta-ala, m².

Rakennuksen vaipan lämpöhäviön vertailuarvo lasketaan käyttämällä lämpimän, erityisen lämpimän tai jäähdytettävän kylmän tilan rakennusosien lämmönläpäisykertoimina seuraavia vertailuarvoja:

a) seinä	0,17 W/(m^2 K);
b) massiivipuuseinä, jonka keskimääräinen paksuus on vähintään 180 mm	0,40 W/(m^2 K);
c) yläpohja ja ulkoilmaan rajoittuva alapohja	0,09 W/(m^2 K);
d) ryömintätilaan rajoittuva alapohja, jossa tuuletusaukkojen määrä enintään 8 promillea alapohjan pinta-alasta	0,17 W/(m^2 K);

e) maata vasten oleva rakennusosa	0,16 W/(m^2 K);
f) ikkuna, kattoikkuna, ovi, kattovalokupu, savunpoisto- ja uloskäyntiluukku	1,0 W/(m^2 K).

Loma-asumiseen suunniteltavan pientalon, joka on tarkoitettu käytettäväksi neljä kuukautta tai enemmän vuodessa, sekä rakennuksen puolilämpimän tilan laskennassa rakennuksen vaipan lämpöhäviön vertailuarvoina käytetään seuraavia rakennusosien lämmönläpäisykertoimien arvoja:

a) seinä	0,26 W/(m^2 K);
b) massiivipuuseinä, jonka rakenteen keskimääräinen paksuus vähintään 180 mm	0,60 W/(m^2 K);
c) yläpohja ja ulkoilmaan rajoittuva alapohja	0,14 W/(m^2 K);
d) ryömintätilaan rajoittuva alapohja, jossa tuuletusaukkojen määrä enintään 8 promillea alapohjan pinta-alasta	0,26 W/(m^2 K);
e) maata vasten oleva rakennusosa	0,24 W/(m^2 K);
f) ikkuna, kattoikkuna, ovi, kattovalokupu, savunpoisto- ja uloskäyntiluukku	1,4 W/(m^2 K).

Rakennuksen yhteenlasketun ikkunapinta-alan vertailuarvo on 15 prosenttia rakennuksen kokonaan tai osittain maanpäällisten kerrosten kerrostasoalojen yhteismäärästä, mutta kuitenkin enintään 50 prosenttia rakennuksen julkisivupinta-alasta. Ikkunan pinta-ala lasketaan ikkunan kehän ulkomittojen mukaan.

Laskennassa käytetään suunnitellun rakennuksen koko- ja geometriatietoja. Rakennuksen vaipan eri rakennusosien pinta-alat määritetään rakennuksen kokonaissisämittojen mukaan.

Rakennuksen suunnitteluratkaisun vaipan lämpöhäviön laskennassa käytetään suunniteltuja rakennusosakohtaisia lämmönläpäisykertoimia ja ikkunapinta-aloja.

9 §
Rakennuksen vuotoilman lämpöhäviö

Rakennuksen vuotoilman lämpöhäviö lasketaan kaavalla:

$$H_{vuotoilma} = \rho_i \mathrm{c}_{\mathrm{pi}} \mathrm{q}_{\mathrm{v,\,vuotoilma}}$$

jossa:

$H_{vuotoilma}$ on vuotoilman lämpöhäviö, W/K;

ρ_i on ilman tiheys, 1,2 kg/m³;

c_{pi} on ilman ominaislämpökapasiteetti, 1000 Ws/(kgK);

$q_{v,vuotoilma}$ on vuotoilmavirta, m³/s.

Vuotoilmavirta $q_{v,vuotoilma}$ lasketaan kaavalla:

$$q_{v,vuotoilma} = \frac{q_{50}}{3600 \cdot x} A_{vaippa}$$

jossa:

$q_{v,vuotoilma}$ on vuotoilmavirta, m³/s;

q_{50} on rakennusvaipan ilmanvuotoluku, $m^3/(h \cdot m^2)$;

A_{vaippa} on rakennusvaipan pinta-ala, m^2;

x on kerroin, joka on yksikerroksisille rakennuksille 35, kaksikerroksisille 24, kolmi- ja nelikerroksisille 20 ja näitä korkeammille rakennuksille 15;

3600 on kerroin, joka muuttaa ilmavirran yksiköstä m^3/h yksikköön m^3/s.